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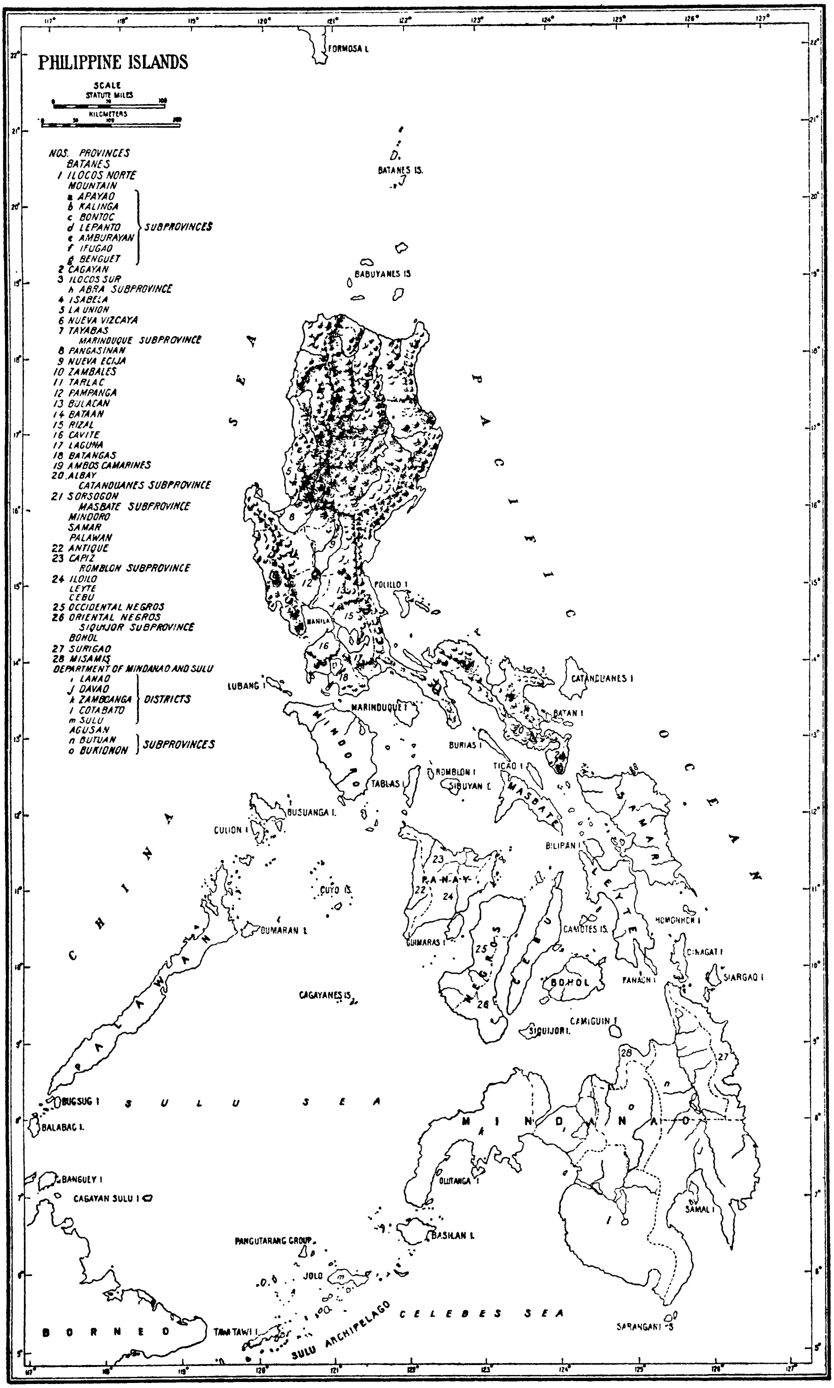

THE PHILIPPINE ISLANDS, SHOWING PRINCIPAL RIVERS AND MOUNTAINS OF LUZON.

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THE SOILS OF THE ISLAND OF LUZON

By ALVIN J. COX and A. S. ARGÜELLES

(*From the Bureau of Science, Manila, P. I.*)

Seven plates, 3 text figures, and 1 map

Luzon, the largest and best known island of the Philippine Archipelago, has an area of 118,620 square kilometers, and lies between the parallels of latitude 12° 30′ and 18° 40′ north and between the meridians of longitude 119° 40′ and 124° 10′ east. The principal rivers of the island, in the order of their length, drainage basin, and navigability, are the Cagayan, the Pampanga, the Agno, and the Abra. The first of these has a length of over 300 kilometers, and the last has about one-half that length. There are many other streams, but most of them are comparatively short and of less importance. A Y-shaped system of mountain ranges running approximately north and south forms the skeleton of the island and also the divide for the waters flowing to the Pacific, those flowing northward by the Cagayan River, and those flowing to the China Sea. This system of mountain ranges is also largely accountable for the amount and distribution of the rainfall. The western portion of the island has fairly well-defined dry and wet seasons, and in general the eastern portion has a rainfall equitably distributed throughout the year. This differentiation of rainfall into the eastern and western types is not absolute, but it can be used in the selection of the areas in which certain crops may be produced and in the determination of how the soil may best be utilized. In Rizal,

Bulacan, and Bataan Provinces and in parts of others; for example, Zambales, Cavite, and Batangas, the dry season is very pronounced.

The humidity which regulates plant transpiration is only second in importance to rainfall. There is not the same marked variation in the mean humidity of the eastern and western zones as in the rainfall, but a close association of the two factors is evident.

All the conditions which influence the soil must be taken into account, for any one may become a controlling factor in the production and quality of crops. Climatic and physical conditions are as important as the chemistry of the mineral matter. A discussion of the influence of rainfall; humidity; mean, maximum, and minimum temperatures; the temperature under the surface of the ground; the amount of light and sunshine; winds and evaporation of the soil moisture; exposure; altitude; etc. on the soil has already been given in a paper on Philippine soils and some of the factors which influence them.[1] There is so little variation in most of the climatic factors in the Philippines that, in the comparison of one region with another, practically all of them, except rainfall, drop out of consideration. Alternations of wet and dry periods often show marked differences in vegetation, and frequently the prevalence of any particular type is directly correlated with the rainfall. It is remarkable how certain crops; such as, coconuts, hemp, and tobacco, which depend upon a rainfall well distributed throughout the year, not only are restricted to the eastern rain zone but completely coincide with it.[2]

The mineral constituents of a soil may indicate high fertility, but the physical components (the amount of humus[3] and unhumified organic matter and the size and shape of the inorganic grains) may be such as to counteract this. The agricultural value of soils is determined not only by chemical composition and climatic and local conditions, but also in many cases by their physical character. There are instances of soils identical in every respect, except with regard to physical texture, which show a marked difference in crops. Some crops are most economically grown and thrive best in loose mellow soil, while others require "heavy" soil with strong retentive power for moisture.

[1] Cox, Alvin J., *This Journal, Sec. A* (1911), **6**, 281, *et seq.*
[2] Cox, *loc. cit.*, 300.
[3] The complex organic product of decomposition.

The different sizes of sand and silt generally constitute the bulk of a given soil mass, and the relative proportions of these largely determine the cultural qualities. To be productive, a soil must have sand, silt, clay, and humus in the proper relations and conditions in both the surface and the substratum to provide drainage with the given topography, aëration, movement, and distribution of the moisture and soluble constituents of the soil; and water-holding and -absorbing power, required by a given crop and water supply; as well as the proper proportion of the different essential inorganic constituents. These factors are incapable of alteration as a whole, but it has been found practicable to modify and adapt some of them to local conditions and desirable crops. Generally, it is not difficult to increase or diminish the water supply and the tenacity of the soil. Unsatisfactory water-holding capacity and cohesiveness sometimes have parallel causes and possible remedies. Both may be economically increased in the case of some sandy soils by the admixture of a small amount of clay, but only in case the clay forms the subsoil or is near at hand. This has been practiced effectively in some places in England. Humus, aside from being a source of plant food, plays an important rôle in the physical behavior of a soil. The humus substances are gelatinous when moist, do not possess marked plasticity nor adhesiveness, but have the power of retaining both gases and moisture in large quantities. For the latter reason, another way to increase the moisture-retaining power and the tenacity of sandy soils is to increase the humus content. For limited areas barnyard manure may be used effectively to increase the content of organic matter, but for large tracts it is more practicable and economical to grow legumes and plow them under as green manure. The coherence of sand, silt, lime, and humus is greatest when they hold sufficient water to fill all interstices between their particles, and as they dry the coherence decreases. On the other hand, clay increases in coherence as it dries, and at last becomes a hard solid mass.[4] Therefore, it is essential in the control of the water-holding capacity and coherence of a soil that the constituents be properly proportioned. The chemical composition of a soil materially influences its physical properties, but other factors being equal clay probably has the greatest individual effect upon the mechanical structure in that the maintenance of floccules and tilth depends thereupon. The heaviness of a soil is

[4] Warington, Physical Properties of Soils. London (1900), 25.

greatly influenced by the colloidality of the clay, and depends largely on the total amount of the constituents finer than 0.05 millimeter average diameter; it is usually difficult to work soils containing over 75 per cent of these, even though the loss on ignition is high, and still more difficult the greater the proportion of clay becomes. A large percentage of silt and a small percentage of clay is the easiest to work of any fine soil. A little too much water in a soil of this type makes it very sticky, and the percentage of water may be so high as to make it impossible to work it. If it could be plowed, its condition would be even worse, for it would turn over, dry out, and harden in chunks without being pulverized. There is an optimum percentage of water in any soil when it works best, but especially in such a soil, and the only plow that will scour well in the latter is one with both mold board and share of the right shape and made of the finest soft center highly polished steel. When such a soil dries out, a very strong plow and a great deal of power are necessary to plow it, and even then it is very hard to put the ground in tillable shape owing to the hard lumps. Colloidal clay renders a soil comparatively impervious to water, and imparts to it a maximum plasticity. Up to a certain point, there is coincidence of plasticity and bonding power, and several of the other physical properties stand in close relation to the former, so that tillage of a very plastic clay soil is almost impossible. On the other hand, the same soil becomes pervious to water, and a good tilth may be maintained when the clay is coagulated. These facts are of great importance in actual tillage operations, for excessive tenacity prevents proper root development and fosters the retention of an excessive amount of moisture in the rainy season and the formation of a hard compact mass in the dry season.

Roland [5] gives the following:

> The ways of decreasing the plasticity, as: First, by the addition of hydroxyl ions, lime water being the cheapest reagent for this purpose. If the concentration of the hydroxyl ions of the lime water is too low for some clays, it may be increased by the addition of sodium hydroxide solution or any strong base combined with a weak acid. The latter class is represented by phosphates, silicates, etc.

This method of coagulating colloids has found wide application in practical farming. The influence of clay in a clayey soil may be modified and the physical composition changed by the addition of humus, sand, burnt clay, and lime, all of which

[5] Sprechsaal. Coburg (1906), 42, 1371.

reduce the tenacity of clay. In clayey soils the presence of humus establishes conditions favorable to aëration, bacterial activities, increased permeability to water and circulation of the soil moisture, and better tilth, and probably renders the mineral plant nutriment more available. The addition of sand to improve clays is uneconomical on account of the large amount of sand necessary materially to change the texture. The application of burnt clay has been found of occasional practical value. The application of limestone or burnt lime has found the widest application in correcting most clayey soils. Burnt lime is uneconomical and undesirable as it tends to dissipate the organic matter. Air-slaked lime, pulverized limestone, or ground oyster shells which contain the lime largely in the form of carbonate have been found least injurious to the organic matter and more beneficial to the crops than any other form. It is usually unnecessary to apply more than from 25 to 30 tons of limestone or from 10 to 15 tons of lime per hectare. In some cases it is better to supplement this by an addition of organic matter, in which case the amount of lime may be decreased and new applications made at intervals, as indicated by field observations.

Lowering the temperature, which has also to do with the colloids of clay, increases the plasticity of clays, and raising the temperature decreases the plasticity. The effect is a very slow one, but may explain what seems to be apparent—that it is easier to cultivate a very clayey soil in a tropical country than in a cold climate.

The effects of plowing, fallowing, draining, rotation of crops, and manuring are all associated in one way or another with the conservation of the plant food and bacterial activity in the soil; with changes in the organic matter, physical composition, and water supply of the soil necessary to maintain productivity; and with the root development of the plants. The above considerations have largely to do with the improvement of the surface soil, but under certain circumstances heavy soils may be effectively and permanently remedied by proper treatment of the soil substratum. Cases occur where the physical texture of the surface soil is satisfactory, but the subsoil is sufficiently clayey to hinder proper drainage and to cause the water to collect on top of the subsoil and rise to such height as to be detrimental to the growing crop. Depending on the circumstances, drainage, subsoil plowing, or similar treatment is the only recourse. The beneficial effect is usually immediate.

The use which can be made of the soils of Luzon and the

character of crops that can be grown have been largely worked out by trial. There is no great need of changing the varieties of crops actually grown, but there are tracts of land where these can be much extended and improved and some new crops might be profitably introduced. There are many differences in agricultural practices, and agriculture has attained higher development in some districts than in others. The best methods used by any section should be extended to every other district possessing the same soil and climatic characteristics, special seed selection and rotation of crops should be generally practiced, and the most improved agricultural practices should be introduced among all the farmers.

With the practice of improved cultural methods and resultant greater yields, a corresponding drain upon the fertility of the soil will follow. Despite the prevalent idea that the fertility of Philippine soils is almost inexhaustible, the practical experience of many farmers is that the land "runs down" after years of continuous cultivation and the crop returns diminish year by year. A careful laboratory investigation and field experiments will usually show the cause and offer a remedy for this.

Investigators have found that the principal causes of the diminished crop production after years of continuous cultivation are generally the toxic, bacterial, physical, and chemical conditions of the soil. Differences of opinion exist as to which of the above factors predominate, but each determines productivity to a greater or less extent. These factors are so interdependent that a possible treatment for one may affect several or all of the others.

TOXIC EXCRETA

Humboldt and De Candolle[6] and more recently Schreiner and Reed[7] have considered the toxic excreta of plants as a factor in soil fertility. The former[8] suggested the idea of the secretion of poisonous excreta by plants as an explanation of the benefit derived from the practice of the rotation of crops, and the latter[9] have shown that it is reasonable to believe that toxic excreta of plants inhibit the growth of the same species of plants and thus play a part in diminishing the fertility of lands continuously cultivated in a given crop. These deleterious organic

[6] *Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1895), 22, 174.
[7] *Bull. U. S. Dept. Agr., Bur. Soils* (1907), 40, 5.
[8] *Ibid.*, 37–38; Physiologie Vegetale (1832), 3, 1474.
[9] *Loc. cit.*, 38.

excreta may be destroyed or their injurious effect neutralized by proper cultivation, the action of microörganisms in the soil, the oxidizing power of roots themselves, and by the action of fertilizers. Schreiner and his associates[10] have recently carried on many interesting experiments which bear upon the complicated question of soil fertility, but their results will need to be thoroughly tested under actual field conditions.

BACTERIA IN THE SOIL

It is a recognized fact that certain bacteria play a conspicuous part in the growth of plants. Bacteria are greatest in number near the surface, decrease with the depth, and practically disappear at 2 meters more or less, depending on the porosity of the soil, the moisture, temperature conditions, and the physical and chemical nature of the soil. Hilgard[11] found that a high humus content in a soil is favorable to bacterial development, confirming the fact that organic matter in the soil is conducive to increased bacterial activity. A gram of moist surface soil may contain fifteen million bacteria. Only aërobic bacteria play an important rôle in soil fertility. Their function is not well established, but it is probable that they take part in breaking down the inorganic constituents into available form for the plants and in improving the tilth of the soil.

The ammonia-forming, nitrifying, denitrifying, and nitrogen-fixing bacteria are important groups of microörganisms. A conspicuous function is their part in the degradation process of nitrogenous organic matter. The chemical reactions involved in this degradation vary with the conditions involved.[12] If it takes place in the presence of a supply of oxygen (the process of decay), such as in a light well-aërated soil, it differs in speed and other essentials from that which takes place when oxygen is conspicuously absent, as in heavy clay or tight loam soil (the process of putrefaction), but in both cases the process is the simplification of nitrogenous organic substances, a product of which is ammonia.

Ammonia-forming bacteria.—It has been shown by Muntz[13] and Goudon that ammonification does not take place in sterile

[10] *Bull. U. S. Dept. Agr., Bur. Soils* (1908), **53**; (1910), **74**; (1911), **77**; (1911), **80**; (1911), **83**.

[11] Soils, New York (1907), 144.

[12] *Cf. Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1907), **194**, 48–49; Wellny, Die Zersetzung der organischen Stoffe (1897), 2; Flügge, Die Mikroorganismen, 3d ed. (1896), **1**, 254.

[13] *Compt. rend. Acad. sci.* (1893), **116**, 395; *Ann. Agron.* (1893), **19**, 209; *Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1907), **194**, 50.

soils and that microörganisms have the exclusive power of forming ammonia from nitrogenous organic matter, and Remy[14] has shown that the ammonification power of soil in a general way measures the amounts of nitrogen available for the growing crop.

Nitrifying bacteria.—Nitrifying bacteria, under proper conditions, convert ammonia into nitrites and nitrates.

Denitrifying bacteria.—Denitrifying bacteria consist of those which merely reduce nitrates to nitrites and progressively to ammonia, which does not necessarily involve loss of nitrogen, and those that convert the nitrates and nitrites into gaseous nitrogen which is thereby lost from the soil.[15] The organisms causing the liberation of soil nitrate as gaseous nitrogen have been found to be present in fresh horse dung and also on the surface of old straw.[16] When the horse dung has become rotted, denitrifying bacteria seem to have disappeared, giving way to nitrifying organisms.

Nitrogen fixation.—The processes of ammonification, nitrification, and denitrification have simply to do with the existing supply of nitrogen in the soil with reference to its retention or liberation from the soil, while the fixation of atmospheric nitrogen by soil microörganisms is one of vital importance in increasing the nitrogen content of the soil.[17] For centuries it has been recognized that long-cultivated soils when left to themselves for a number of years partially recover their lost fertility. It was later recognized that such fertility accumulation is largely due to increase in the content of nitrogen. Later it was explained by Boussingault[18] as being mostly the work of microörganisms. The discovery by Hellriegel and Wilfrath of the fixation of nitrogen in the root tubercles of legumes, together with the studies of Berthelot and other investigators, definitely established that increase in nitrogen in the soil is due to fixation by bacteria that may be living within the soil itself (nonsymbiotic) or those living within the root tubercles of legumes (symbiotic).

[14] *Centralbl. f. Bakt., etc.*, 2 Abt. (1902), **8**, 657; *Fünfte Internat. Kong. Angew. Chem.* (Behn) (1903), 793.

[15] *Loc. cit.*, Hilgard, Soils, 146; Vorhees and Lipman, A Review of Investigations in Soil Bacteriology. *Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1907), **194**, 71.

[16] *Loc. cit.*, Hilgard, Soils. 148; *Bull. Bur. Agr. Intell.* (1913), 4, 1528–9.

[17] *Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1907), **194**, 76.

[18] *Ibid.*, 76.

About thirty years ago, Berthelot observed that nitrogen fixation takes place in bare and uncultivated soils and attributed such gain to the activity of certain forms of microörganism,[19] and Garlach and Vogel, Koch, Vorhees and Lipman, and other investigators have conclusively shown that members of the azotobacter group of aërobic bacilli can fix nitrogen. However, further investigation would be necessary before the certainty of the value[20] to practical agriculture of nonsymbiotic bacteria can be definitely established.

The fixation of nitrogen by bacteria within root tubercles is of comparatively recent development. Hellriegel[21] first discovered that legume tubercles are due to bacterial activity and that the root tubercles contain the atmospheric nitrogen stored up by bacteria. Where tubercles develop in the legumes and soil conditions are satisfactory to bacterial growth, experiments have shown the fixation of as much as 200 pounds of nitrogen per acre in the case of crimson clover. This is amply confirmed by similar experiments in the different experimental stations where proper soil conditions have been established.

Some soils do not contain the necessary bacteria for desirable legumes to be grown, and therefore the help of bacteria cannot be utilized to increase the supply of nitrogen. This can be remedied when proper soil conditions are attained by inoculating the seed with the desired bacteria.

For each class of bacteria there are optimum conditions of temperature, moisture, aëration, alkalinity, etc. for the greatest activity.[22] In neutral or acid soils the activity of nitrification bacteria is stopped. A sufficient quantity or an excess of a base must be present to unite with the acids formed by the oxidation of ammonia. The most favorable substances for this purpose are limestone and dolomite, an excess of which does no harm. These principal conditions inducing bacterial activity have had practical application in modern agriculture and have given beneficial returns by increased production of crops. One of the most striking is the common practice of inoculating the

[19] *Ibid.*, 81.

[20] Hopkins, Soil fertility and Permanent Agriculture. Ginn & Co., N. Y. (1910), 225.

[21] Tagebl. 59. Versamml. deut. Naturf. u. Aerzte. Berlin (1886), No. 7, 290; *Bull. U. S. Dept. Agr., Off. Exp. Sta.* (1907), 194, 89.

[22] R. Warington [*Trans. Chem. Soc.* (1878), 44; (1879), 429; (1884), 637; (1891), 484] has investigated the conditions affecting the activity of some of the organized ferments.

soil with certain beneficial bacteria after proper conditions have been found suitable or established.

In this paper, we do not give complete data with regard to the soils of Luzon, but we desire to place on record as many facts as possible concerning the fertility of some of the agricultural sections of Luzon, based on chemical and physical analyses and to a certain extent on such field observations as we have been able to segregate. In some sections of the island we have been able to carry on our work much more thoroughly than in others. From certain sections we have little data, except an occasional analysis, which shows the general nature of the soil. Where the chemical and physical data are fairly complete, they may be taken together with the meteorological and agricultural data of the district and used not only to develop the district itself, but to interpret the probabilities of success of certain crops in new districts.

No analysis is more accurate than the sample which it represents; therefore, the errors of sampling should be reduced to a minimum. All samples were collected according to the directions for taking soil samples,[23] already published.

THE CHEMICAL ANALYSIS

The chemical analysis aims to give a general idea of the potential fertility of the soil, and in a way measures the crop-producing power of a given land, provided that the climatic conditions, physical texture, and bacterial activities are satisfactory. Hilgard,[24] from practical experience and extensive investigations, found that this is invariably true with virgin soils, while with soils that have been cultivated for centuries under different cultural methods and in different crops other factors not readily differentiated by chemical analysis alone are presented.

There are ten elements essential to the proper growth of plants as follows:[25] Carbon, oxygen, and hydrogen, the sources of which are air and water; phosphorus, potassium, and nitrogen, which are sometimes deficient in soils and have commercial value as plant food; sulphur, calcium, iron, and magnesium, which are required by plants in small amounts and are rarely deficient in soils. Silicon, aluminium, sodium, chlorine, and manganese are also commonly found in plants.

[23] Cox, *This Journal, Sec. A* (1911), 6, 326.
[24] *Loc. cit.*, Soils, 325, 343.
[25] *Loc. cit.*, Hopkins, Soil, etc., 13.

In general, the concern of the chemist with reference to plant food supply is the phosphorus, potassium, and nitrogen content, for, if the percentage of any one of these existing in the soil falls below that necessary to yield a nutrient solution of the concentration demanded during the period of most active assimilation, the productive capacity of the soil may be questioned.[26] The quantity of organic matter and calcium present are also of special interest in that they affect the availability of plant nutrients, the bacterial activity, and the physical texture of the soil.

Two aspects to be determined by chemical soil analysis are clearly distinguishable: First, the permanent productive value, the prevention of undue drain by crops, and the regulation of the necessary elements of plant food by the addition of fertilizers, which is of vital importance in rational agriculture; secondly, the immediate producing capacity, which is chiefly concerned with immediate returns. The determination of these two factors is entirely different, even though the results and their causes may usually be intimately correlated.

The soil is the result of the degradation and disintegration of rocks. Some of the inorganic plant food is still in the mineral condition in which it was originally derived from the parent rock. The degree of disintegration usually determines the degree of availability. The inorganic plant food elements may be classified with reference to whether they are (1) soluble in water, (2) in acid, or (3) can be dissolved only by alkali-carbonate fusion.

(1) The water-soluble plant food elements constitute the readily available portion, but an excess in this form would be disadvantageous, as the greater part would be lost by being leached out and washed away by heavy rains. An excess of some soluble salts is a great detriment, as shown by the poor growth of plants on saline or alkali lands.

[26] This percentage is usually assumed as 0.1. It is evident that this is influenced by the physical and chemical conditions. The circulation of an abundant supply and subsequent evaporation of water increases the concentration of the soil solution so that the requisite percentage is probably less when the physical and chemical conditions are favorable. It unquestionably varies with a great many interdependent factors which cannot be determined without the employment of methods based on physical chemistry.

When the naturally accumulated concentration of nutrient solution is too low, it can be efficiently increased artificially by the addition of an easily soluble supply.

(2) It is desirable that the greater portion should be the "reserve" food material; that is, in the form available to plants only by the solvent action of acids in the soil and the action of the roots of the plants.[27]

King [28] found that in some soils enough plant nutriment for a season's crop may be dissolved by distilled water alone, if the soil be subjected to repeated leachings and drying at 110°C., but there were striking differences in the amount of leachings from samples of known productive capacity and others of low production.

Snyder [29] found that soil leachings failed to supply a sufficient amount of plant food to produce normal plants of wheat, oats, and barley and that the plants obtain a large portion of their food from forms which are insoluble in water.

(3) Those soil ingredients that cannot be brought into solution except by alkali carbonate fusion or hydrofluoric acid treatment constitute the unchanged minerals, and under ordinary conditions are of no practical value as a source of plant food supply, at least, for many years.

The water- and acid-soluble ingredients include the supply of plant food which presumably "will become available in a period of time in which we are interested" by the reactions which take place in the soil by the application of scientific management and cultural methods. These have been separated and determined. The methods used were substantially those of the Association of Official Agricultural Chemists.[30] The results are given on the basis of a sample dried to a constant weight at 105°C.

All chemical analyses were made on that portion which passed a 1-millimeter screen ("fine earth"). The sand grains larger than this are considered to be composed of quartz more or less

[27] The equilibria between the solid, liquid, and gaseous components of soils, although they have been extensively studied, are so complicated that much remains to be discovered. Calcium and magnesium carbonates and phosphates are acted upon by the weak acids in the soil and the roots of plants, and are thereby made available as plant food. Tricalcium phosphate is difficultly soluble in the soil moisture, and is generally considered not easily available. Phosphates of aluminium and of iron are extremely slightly acted upon by soil moisture, and are usually not considered as a source of plant food within a reasonable time. These equilibria are important in the fixation of the water-soluble fertilizers applied upon the land, and prevent waste from leaching.

[28] *Loc. cit.*, Hilgard, Soils, 323.

[29] *Bull. Minn. Agr. Exp. Sta.* (1905), **89**, 198–200.

[30] *Bull. U. S. Dept. Agr., Bur. Chem.* (1908), **107** (Revised).

pulverized. Quartz is practically inert as a source of plant food, and barrenness is commonly associated with sandy land. This is not necessarily true in arid regions where kaolinization and disintegration take place very slowly. In such cases the larger grains may contain potentially available plant food, but in the case of Philippine soils under tropical conditions there has been rapid decomposition of the particles of sand and gravel and the detritus on a 1-millimeter sieve is usually very small, and we believe the portion passing a sieve of this size contains practically all the constituents from which the plant derives its food and includes all that should be termed "fine earth" or soil.[31]

From the following analyses of the chlorhydric soil extracts one can deduce the requirements as to mineral plant food of all the soils we have investigated. Soils that show a very low percentage of any one element necessary to plant nutrition will yield a low crop production, if not at once, at least within a few years after cultivation has begun unless remedied by supplying that element in the form of fertilizer. On the other hand, any essential element shown by analysis to be present in abundant amount, especially in virgin soils, may generally be assumed to be the last to become deficient in the course of crop production.

THE PHYSICAL ANALYSIS

The physical analyses were made with a Schone apparatus according to a method outlined by one of us.[32] The air-dried soils were disintegrated by shaking in water, and special effort was made to secure complete disintegration of the aggregates, without which there is no constant means of comparison, before they were separated into the individual fractions.[33]

Hilgard[34] has proposed to determine the mechanical structures of soils by photographing the various fractions in glass tubes of uniform bore, and adds that a series of such tubes would describe a curve of the soil composition. We have carried on analyses to test the accuracy of this method. It is very difficult to photograph glass tubes because they reflect light, and

[31] If there were a large detritus on a 1-millimeter sieve, the results with respect to certain constituents might appear high and would not fairly represent the composition of the soil.

[32] Cox, *This Journal, Sec. A* (1911), 6, 313.

[33] Oven-dried soils are apt to form hard aggregates which cannot be disintegrated by shaking, and the percentages of the coarser grains may be greatly increased.

[34] *Loc. cit.*, Soils, 94.

we have substituted therefor a block of wood having adjacent uniform vertical grooves faced with a glass plate. Any such method assumes that the percentage of voids in the material with the different sizes of the grains is identical, and for this reason cannot be strictly accurate. Furthermore, clay and silt cake in drying, and care has to be exercised that these are broken up. We found a great variation in the sum of linear measurement of the fractions of samples of different soils of the same weight. Comparative determinations by weight and by measurement are as follows:

TABLE I.—*Mechanical analyses of soils comparing determinations by weight and by measurement.*

Source.	No.	Coarse sand, 1-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.10 mm.	Very fine sand, 0.10-0.05 mm.	Silt, 0.05-0.01 mm.	Fine silt, 0.01-0.002 mm.	Clay less than 0.002 mm.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Batangas	[a] 5	0.8	3.7	9.8	13.9	19.0	40.9	11.9
Do	[b] 5	1.1	4.2	8.7	12.1	19.2	41.9	12.8
Do	[a] 10	0.6	2.7	16.9	11.4	14.4	31.2	22.8
Do	[b] 10	1.3	7.6	16.8	13.2	19.5	31.3	10.3
Do	[a] 15	1.0	2.7	10.9	15.1	19.0	34.7	17.1
Do	[b] 15	1.3	4.1	12.0	22.1	18.1	31.6	10.8
Do	[a] 16	0.5	1.9	20.0	14.8	6.3	29.3	27.2
Do	[b] 16	1.0	7.6	16.8	14.8	6.6	28.9	24.3
Do	[a] 28	0.7	2.9	9.5	12.6	23.0	32.4	18.9
Do	[b] 28	0.7	1.9	10.8	12.2	24.1	32.8	17.5
Do	[a] 29	0.1	0.6	16.6	31.7	17.7	26.0	7.3
Do	[b] 29	0.7	4.7	17.5	27.8	15.4	26.4	7.5
Do	[a] 30	0.2	0.8	18.5	29.4	18.3	24.3	8.5
Do	[b] 30	0.1	1.6	15.0	30.0	18.9	25.6	8.8
Do	[a] 36	2.1	5.6	23.6	18.4	15.5	23.7	11.1
Do	[b] 36	3.4	11.9	18.2	16.3	15.4	24.3	10.5
Do	[a] 37	2.9	5.2	13.3	15.5	19.2	31.8	12.1
Do	[b] 37	2.5	5.2	9.2	15.8	20.9	35.8	10.6
Do	[a] 38	2.1	12.0	27.2	9.5	15.6	21.0	12.6
Do	[b] 38	2.1	8.8	20.1	12.4	11.9	28.3	16.4
Do	[a] 41	2.8	5.4	14.6	19.8	15.3	30.6	11.5
Do	[b] 41	2.8	5.9	10.2	17.3	15.0	37.4	11.4
Mountain Province	[a] 3	1.2	4.0	8.1	7.9	8.9	42.1	27.8
Do	[b] 3	1.1	4.6	7.3	7.7	10.8	41.8	26.7
Do	[a] 8	4.1	7.2	18.7	13.4	13.6	26.4	16.6
Do	[b] 8	3.4	7.9	14.4	13.7	16.5	33.3	11.8
Do	[a] 12	3.5	5.4	18.7	19.9	15.3	29.2	8.0
Do	[b] 12	4.2	8.5	10.7	16.1	19.7	32.7	8.1
Do	[a] 20	5.6	10.6	25.2	13.6	12.1	21.8	11.1
Do	[b] 20	13.3	12.9	12.6	13.6	15.0	22.5	10.1
Do	[a] 33	24.6	25.1	5.2	15.5	6.3	9.9	13.4
Do	[b] 33	27.9	26.6	7.3	16.3	7.2	6.7	8.0
Cagayan	[a] 7	----------	1.5	23.6	36.7	12.0	21.0	5.2
Do	[b] 7	----------	1.9	20.6	35.7	11.2	23.5	7.1
Do	[a] 8	----------	1.1	18.9	37.2	12.4	23.4	6.0
Do	[b] 8	----------	1.2	16.0	36.8	12.7	26.0	7.3

[a] By weight. [b] By measurement.

TABLE I.—*Mechanical analyses of soils, etc.*—Continued.

Source.	No.	Coarse sand, 1-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.10 mm.	Very fine sand, 0.10-0.05 mm.	Silt, 0.05-0.01 mm.	Fine silt, 0.01-0.002 mm.	Clay less than 0.002 mm.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Cagayan	[a] 9		0.4	26.8	34.6	12.7	19.7	5.8
Do	[b] 9		0.9	22.2	32.8	12.1	24.6	7.4
Do	[a] 10		0.4	18.7	34.0	16.7	23.9	6.3
Do	[b] 10		0.6	14.6	31.6	16.4	28.3	8.5
Do	[a] 11		0.5	8.3	34.0	16.1	33.7	7.4
Do	[b] 11		1.2	7.5	32.6	14.9	35.2	8.6
Do	[a] 12		0.6	7.4	20.7	1.7	59.4	10.2
Do	[b] 12		0.9	7.6	20.1	2.4	55.9	13.1
Do	[a] 13		3.1	16.3	23.1	20.2	28.0	9.3
Do	[b] 13		3.0	14.7	21.1	20.1	30.7	10.4
Laguna	[a] 1	0.8	3.9	9.0	11.1	12.2	35.5	27.5
Do	[b] 1	0.3	3.3	7.4	12.3	12.8	35.3	28.6
Do	[a] 2	1.1	3.1	5.3	10.2	14.8	34.1	31.4
Do	[b] 2	0.9	3.4	5.3	11.1	14.8	34.0	30.5
Do	[a] 3	0.5	1.9	6.6	9.0	9.2	34.0	38.8
Do	[b] 3	0.3	1.3	5.4	9.1	10.5	33.5	40.0
Do	[a] 4	2.5	4.9	30.5	18.6	10.7	18.7	14.1
Do	[b] 4	1.4	4.5	25.5	18.6	12.1	21.0	16.9
Do	[a] 5	0.4	2.1	17.5	15.6	11.2	23.5	29.7
Do	[b] 5	0.5	1.5	14.2	14.2	11.5	27.2	30.9
Do	[a] 6	1.3	8.8	32.7	18.3	9.0	17.1	12.8
Do	[b] 6	1.4	7.3	26.4	17.4	10.0	20.1	17.4
Do	[a] 7	3.5	14.8	36.5	14.2	10.3	12.8	7.9
Do	[b] 7	3.4	13.2	29.6	14.1	11.6	16.8	11.3
Do	[a] 8	6.1	10.5	19.5	15.7	14.3	23.4	10.5
Do	[b] 8	4.8	7.5	14.3	14.3	15.4	28.8	15.7
Do	[a] 9	6.4	12.8	17.7	11.4	14.6	24.2	12.9
Do	[b] 9	5.6	9.7	13.8	10.6	15.0	29.7	15.6
Tayabas	[a] 10	1.0	2.7	10.4	15.9	24.1	34.5	11.4
Do	[b] 10	1.0	2.2	6.9	13.9	22.1	39.4	14.5
Do	[a] 13	1.0	3.9	11.3	10.9	22.1	33.3	17.5
Do	[b] 13	1.4	3.6	9.3	11.9	23.4	33.9	16.5
Do	[a] 16	8.8	28.1	38.1	9.8	4.4	5.7	5.1
Do	[b] 16	8.8	24.4	35.4	11.0	5.8	7.3	7.3
Miscellaneous	[a] 1	0.9	3.9	23.0	21.7	12.8	21.0	16.7
Do	[b] 1	0.6	2.8	19.0	25.1	14.2	22.6	15.7
Do	[a] 2	0.4	2.6	7.7	17.3	19.1	39.7	13.2
Do	[b] 2	0.4	2.5	3.8	18.4	19.4	42.8	12.7
Do	[a] 3	0.9	4.6	14.9	13.8	18.1	34.3	16.4
Do	[b] 3	0.6	3.2	11.3	13.7	15.4	38.0	17.8
Do	[a] 4	0.6	14.2	51.6	12.7	5.5	9.6	5.8
Do	[b] 4	0.4	13.3	46.7	14.0	6.7	13.3	5.6
Do	[a] 5	0.2	2.2	41.6	23.6	11.4	14.2	6.8
Do	[b] 5	0.1	1.8	31.7	22.8	11.4	16.7	8.5
Do	[a] 6	0.9	2.9	8.3	11.4	11.9	37.2	27.7
Do	[b] 6	0.7	2.3	3.3	12.0	11.7	41.0	29.0
Do	[a] 7	0.3	1.4	19.1	22.4	17.5	26.5	12.8
Do	[b] 7	0.1	0.9	16.2	22.6	16.5	28.4	15.3
Do	[a] 8	0.4	1.7	8.1	13.5	10.1	40.7	25.5
Do	[b] 8	0.2	1.6	4.6	13.8	9.2	45.6	25.0

[a] By weight. [b] By measurement.

TABLE I.—*Mechanical analyses of soils, etc.*—Continued.

Source.	No.	Coarse sand, 1-0.5 mm.	Medium sand, 0.5-0.25 mm.	Fine sand, 0.25-0.10 mm.	Very fine sand, 0.10-0.05 mm.	Silt, 0.05-0.005 mm.	Fine silt, 0.05-0.002 mm.	Clay less than 0.002 mm.
		Per cent.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Miscellaneous	[a] 9	0.1	0.7	15.5	15.2	13.2	34.6	20.7
Do	[b] 9	----------	1.3	14.3	15.3	13.9	35.2	19.9
Do	[a] 10	0.5	1.8	22.2	32.7	16.3	18.8	7.7
Do	[b] 10	0.5	1.3	19.1	31.5	16.3	21.4	9.8
Do	[a] 11	0.4	2.8	30.7	30.2	7.9	20.2	7.8
Do	[b] 11	0.6	2.3	25.8	31.4	4.4	24.4	11.1
Do	[a] 12	0.4	5.1	30.5	20.7	4.7	19.1	19.5
Do	[b] 12	0.6	3.9	25.9	22.5	5.1	21.9	20.4
Do	[a] 13	8.3	19.3	27.8	12.1	8.1	15.5	8.9
Do	[b] 13	7.4	15.8	25.3	13.9	9.2	18.1	10.3
Do	[a] 14	10.5	17.9	23.1	11.2	8.9	16.0	12.4
Do	[b] 14	5.5	16.1	21.2	12.5	10.3	18.7	15.7
Do	[a] 15	3.1	17.1	28.8	16.6	11.2	15.7	7.5
Do	[b] 15	3.2	9.9	28.4	20.6	13.5	19.1	5.3

[a] By weight. [b] By measurement.

In the table, the numbers representing the percentages of the coarser and finer fractions are usually, respectively, lower and higher by measurement than by weight. The results by measurement can only approximate those by weight and are satisfactory only for rough work. If it is desired to have a graphic representation of the mechanical structures of the soils, a more accurate and satisfactory way is that suggested by Pratt[35] by plotting the mechanical composition by weight of a surface soil and its subsoil, so that not only the relative proportion of the different grain sizes is shown, but also the physical composition as a whole.

Where the data warrant it, we will discuss a region independently.

BATANGAS

We have carried on a rather careful survey of this district. This region has been selected for special study because its agricultural fertility is known. We hope that the data here given will help to establish Philippine soil types, and in time, as the work progresses, it may be possible accurately to state what soils are best suited to a given crop and to interpret the results of any soil in its relation to the ideal soil for a given crop. A study of this kind will also aid in the future manuring and fertilizing of the area.

A chain of extinct or quiescent and active volcanoes, which

[35] *This Journal, Sec. A* (1911), 6, 39.

have contributed material for most of the soils of the southern provinces, stretches from Batangas and Laguna Provinces to the extreme southeastern point of Luzon. The soils of Batangas are mostly the result of disintegration of water-laid tuff, agglomerate, etc.,[36] which extend widely over Luzon. Volcanic soils are usually very fertile, and those of Batangas are no exception. The soils of this region are mostly loam or clayey loam, but they occasionally contain a conglomerate phase. There are no heavy clay soils in the whole province. Underlying the surface soil in many places is undecomposed pila rock, and the samples from Taal show a considerable amount of this in the upper layer. The area around Batangas, which contains more types of soil than any other part of this region, is made up of alluvial and littoral deposits.

Dorsey[37] has made a soil survey of the Batangas area. He states that—

> Eleven types of soils of varying agricultural value and differing widely in their origin and method of formation were recognized and mapped. Of the alluvial soils, the Calumpang sandy loam and the Calumpang loam are the most valuable for general farming purposes. Of the residual soils derived in place by the slow decomposition of the underlying rocks, the Lipa loam possesses the greatest natural advantages, while the Talumpoc clay loam is the poorest of all the soils.

His work is the basis for fig. 1.

The types of soils named and described by Dorsey are represented by our samples as follows:

Type of soil.	Sample Nos.
Ibaan clay loam	15, 16, 17, 18, 20, 21, 22, 23, 24, 25, 26, 33, 34, 35, 36, 41, 42, 43, 44.
Lipa	1, 2, 3, 4, 5, 6, 7, 8,
Taysan clay	9, 10, 11, 12, 13, 14.
Malabo waxy clay	None.
Macolod gravelly loam	31, 32.
Talumpoc clay loam	None.
Calumpang loam	27, 28.
Calumpang sandy loam	29, 30.
Calumpang silt loam	37, 38.
Muck	39.
Salt marsh	40.

The locations from which samples 45 to 49 were taken are not shown on the map.

Fig. 1 shows the superficial differentiation of the soils, and Table II gives their chemical analyses.

[36] These have been mapped by Adams, *This Journal, Sec. A* (1910), **5**, 57.
[37] *Bull. P. I. Bur. Agr.* (1903); **3**, 37.

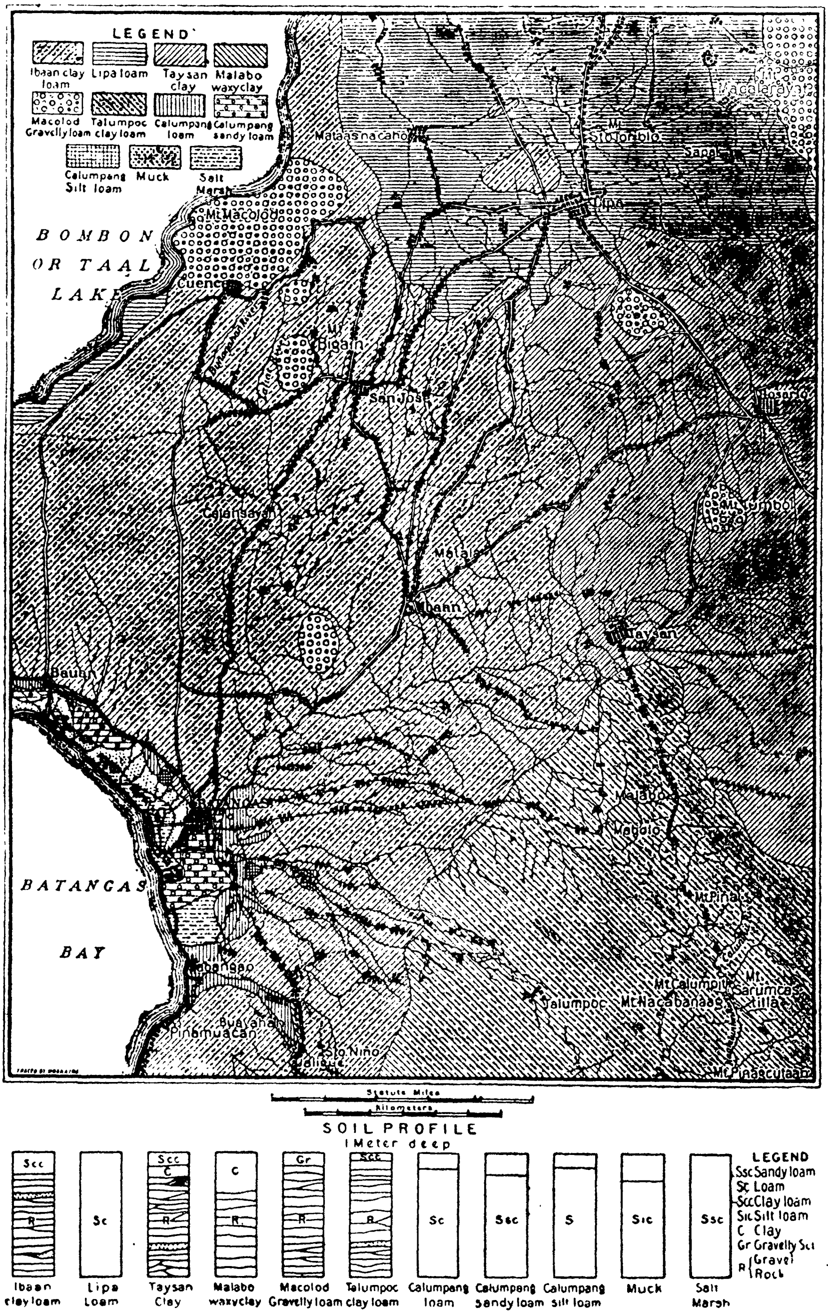

FIG. 1. Types of soils of the Batangas area.

TABLE II.—*Chemical analyses of Batangas soils.*

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Humus.	Soil acidity (percent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
1	0–16	8.77	10.09	0.186	0.177	0.99	0.26	0.309	0.74	2.46	0.00625	98.88	Santo Toribio, Lipa, Batangas.	Produces 150 *cauas* of sugar juice per hectare.[a]
2	16–30	13.74	8.99	0.149	0.184	0.86	0.18	0.253	0.35	2.01	0.00437	97.71	do	A composite sample of varying subsoils.
3	16–30	14.57	11.77	0.089	0.175	0.68	0.57	0.273	0.36	1.61	0.00875	98.97	do	Sample when dark subsoil is excluded.
4	30–50	17.83	12.01	0.081	0.200	0.65	0.20	0.240	0.58	0.95	0.00688	86.21	do	Subsoil to No. 1.
5	0–16	8.45	10.66	0.114	0.170	0.90	0.32	0.279	0.66	2.84	0.00375	99.03	Marawoy, Lipa	Previously produced good crops of sugar cane, rice, and corn, but now uncultivated.
6	16–30	11.41	10.98	0.094	0.235	0.95	0.66	0.336	0.71	2.88	0.00313	99.06	do	Subsoil to No. 5.
7	0–16	11.34	10.99	0.142	0.239	0.68	0.47	0.367	0.77	1.52	0.00563	91.87	Sapak, Lipa	Composite sample of a number of fields.[b]
8	16–30	17.50	11.68	0.092	0.223	1.06	0.47	0.362	0.64	1.00	0.00500	88.00	do	This is underlain by volcanic tuff in certain sections.
9	0–16	7.71	10.71	0.173	0.209	0.87	0.34	0.264	1.17	2.08	0.01000	98.80	Rosario	Rice field in low plain. Production considered good.
10	16–30	17.39	12.33	0.083	0.143	0.85	0.32	0.222	1.04	1.25	0.00625	97.16	do	Subsoil to No. 9.
11	30–60	21.96	12.49	0.097	0.124	1.06	0.28	0.183	0.84	0.96	0.00875	95.38	do	Clay substratum to No. 9.
12	0–16	12.64	11.86	0.172	0.107	0.88	0.39	0.185	0.95	0.97	0.00563	96.16	Taysan	Rice field with hard volcanic tuff as subsoil.[c]
13	0–16	13.75	11.08	0.103	0.072	0.80	0.22	0.233	0.48	1.13	0.00812	97.78	do	At present and for the last two years cultivated in rice.[d]
14	16–30	16.81	11.62	0.069	0.079	0.77	0.19	0.253	0.38	0.74		91.60	do	Subsoil to No. 13.
15	0–16	11.82	10.51	0.133	0.185	0.62	0.27	0.291	0.27	1.47	0.00625	97.68	Matala, Ibaan	Brown loam with clayey subsoil.[e]

[a] Change in character at about 20 centimeters. Up to about eighteen years ago good crops of coffee were grown. Subsequently, the trees were destroyed by insect borers of the genus *Xylotrechus* and by leaf blight of the genus *Hemileia*. Volcanic tuff occurs at from 1 to 2 meters below the surface.

[b] Volcanic tuff is near the surface in many, though not in all, places. The land lies irregularly. The deeper soil is considered to be fertile. Previously, coffee was largely grown, but now rice, corn, and some sugar cane are the usual crops.

[c] It has lain fallow for a number of years. Produces a fair crop. In favorable seasons it is said to have produced 1,500 liters of rice per hectare (cavan) of land. The field is rolling, and is traversed by small brooks.

[d] Previously it has lain fallow for several years. Considered to produce a good crop and superior to No. 12. The field is a rolling plain with clay subsoil.

[e] Produces a good crop of sugar cane. It has been cultivated more or less continuously for over twenty years. It may have been fertilized with bagasse at times. The region yields sugar cane, corn, and rice.

TABLE II.—*Chemical analyses of Batangas soils*—Continued.

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
16	16-30	17.09	10.81	0.079	0.169	0.65	0.23	0.302	0.26	0.84	0.00750	94.55	Matala, Ibaan	Subsoil to No. 15.
17	0-16	9.50	9.79	0.112	0.157	0.42	0.21	0.288	0.27	1.67	0.00500	98.82	Cabisang, Bantasan, Ibaan.	Rice and corn are grown. Considered to produce fairly good crop.[a]
18	16-30	9.31	10.83	0.075	0.186	0.42	0.23	0.272	0.40	1.88	------	98.19	do	Subsoil to No. 17.
20	0-16	11.37	10.00	0.176	0.093	1.43	0.45	0.540	0.46	1.65	0.00437	96.50	Dagatan, Santo Niño, Batangas.	Dark clayey loam, considered to be very productive.[b]
21	16-30	14.82	10.20	0.173	0.090	1.60	0.65	0.598	0.60	1.54	0.00563	94.87	do	Light-colored and sticky clay. 1 meter from volcanic tuff.
22	0-16	12.03	12.47	0.112	0.075	0.93	0.44	0.452	0.42	1.10	0.01314	97.56	Ilaya, Santo Niño, Batangas.	Produces decidedly inferior to No. 20. Subsoil volcanic tuff.
23	0-16	11.26	9.88	0.117	0.070	0.89	0.51	0.445	0.45	1.09	0.00563	97.03	Haligue, Batangas	Rice field, said to produce good crop. District mountainous.
24	16-30	14.19	10.93	0.076	0.037	0.95	0.63	0.344	0.32	0.55	0.00625	95.57	do	Clay subsoil to No. 23. Volcanic tuff 1 meter below surface.[c]
25	0-16	11.42	21.40	0.082	0.072	15.93	2.22	0.465	1.03	0.77	nonacid	94.31	Buayahan, Batangas.	Special type of soil found on moderately steep side of a hill.
26	16-30	11.39	19.60	0.051	0.069	18.04	0.63	0.281	0.39	0.33	nonacid	88.48	do	Reddish clay. About 50 centimeters before volcanic tuff appears.
27	0-16	7.03	6.30	0.100	0.089	1.29	0.33	0.354	0.30	0.97	0.00250	96.78	Libho, Batangas	Rice field.[d]
28	16-30	4.88	9.21	0.099	0.070	1.50	0.48	0.354	0.52	1.34	0.00250	96.69	do	Clayey, and from 1 to 3 meters deep.
29	0-16	10.43	10.68	0.141	0.170	1.19	0.61	0.376	0.41	1.05	0.00688	96.09	Kalero, Batangas	Sugar-cane field of alluvial origin; has been cultivated for years, and produces well.
30	16-30	10.18	9.76	0.094	0.233	1.12	0.38	0.302	0.49	0.73	0.00500	98.68	do	Subsoil to No. 29. Somewhat clayey.
31	0-16	9.57	8.73	0.147	0.264	1.91	0.49	0.456	0.51	1.04	0.00812	93.66	At the foot of Mount Macolot, Cuenca.	Inclined to be gravelly on surface. Yields good crops in corn and rice.
32	16-30	11.06	8.87	0.161	0.274	1.74	0.49	0.407	0.72	1.21	0.00625	96.67	do	Subsoil to No. 31.
33	0-16	8.17	9.09	0.137	0.202	1.12	0.74	0.467	0.46	0.74	0.00563	94.98	Cuenca	Rice and corn field.[e]
34	16-30	11.47	10.14	0.121	0.236	1.25	0.79	0.436	0.52	1.41	0.00750	90.87	do	Subsoil to No. 33.

35	0-16	11.97	8.87	0.114	0.215	1.54	0.64	0.425	0.52	0.89	0.00750	91.11	Bauan	Rice field, and considered to produce fairly well.
36	16-32	12.74	8.93	0.091	0.263	1.43	0.59	0.431	0.54	0.65	0.00688	91.83	do	Somewhat darker than the surface.
37	0-16	10.47	10.05	0.129	0.198	1.22	0.61	0.343	0.40	1.52	0.00437	93.84	Palengke, Batangas.	Sugar cane used to be grown; production good. Rice and corn are now grown.
38	16-30	16.29	10.38	0.128	0.116	1.04	0.53	0.421	0.33	0.82	0.00563	92.66	do	Subsoil to No. 37. Inclined to be sticky volcanic tuff about 60 centimeters from surface.
39	surface	13.31	10.14	0.392	0.036	7.43	0.33	0.444	0.28	3.21		96.89	Tubigan, Batangas	Black marshy soil. Very productive. Rice and forage are grown.[f]
40	surface	5.18	4.80	0.098	0.073	1.56	0.15	0.325	0.96	1.07	nonacid	84.60	Aplaya, Batangas	No crop grown. Salt is made in this place.
41	0-16	9.80	9.55	0.134	0.136	0.95	0.46	0.269	0.34	1.00	0.00563	91.33	Kalansayan, San Jose.	Tobacco was formerly grown, but now fields are planted in rice and corn. Production is good.[g]
42	16-30	10.42	9.84	0.107	0.139	0.71	0.17	0.289	0.25	0.71	0.00625	93.53	do	Subsoil to No. 41.
43	0-16	9.71	10.56	0.197	0.225	0.80	0.49	0.489	0.35	1.78	0.00437	95.81	do	Produces good crops of tobacco, rice, and corn. Darker than No. 41.
44	16-30	9.19	10.23	0.190	0.256	0.90	0.47	0.582	1.15	1.82	0.00563	95.35	do	Somewhat more clayey than surface.
45	0-10	7.29	7.71	0.196	0.231	1.48	0.58	0.826	0.80	1.23	0.00312	92.13	Taal	2 kilometers from Taal, on a line south 20° east.[h]
46	10-30	12.34	7.67	0.114	0.153	1.43	0.45	0.661	1.08	0.77	0.00563	96.19	do	Subsurface to No. 45.
47	at 150	5.59	3.81	0.065	0.064	1.65	0.48	0.727	1.27	0.20	0.00437	88.63	do	Subsoil to No. 45.
48		10.36	11.40	0.157	0.150	1.22	0.24	0.323	0.85	1.09	0.00437	89.80	Santo Tomas, Batangas.	150 meters north of station, on east side of railway.[i]
49		10.27	10.23	0.139	0.164	1.16	0.36	0.291	0.50	1.23	0.00375	98.16	do	The same general district as No. 49.

[a] In places the "volcanic tuff" is near the surface, although on the average it is about 60 centimeters deep. Topography is rolling and inclined to be rough.

[b] Sugar cane used to be grown, and a very good yield was obtained. At present rice and corn are grown. This field has lain fallow for about 3 years.

[c] Rice and corn yield fairly well.

[d] Alluvial silty brown loam, and considered one of the best soils in the region. The region is annually inundated by the overflow from Calumpang River. It has been under cultivation for years, and is considered to yield exceptionally good crops of rice, corn, or sugar cane.

[e] The region is gently rolling, and is considered very productive. The soil is about 1 meter deep.

[f] From 2 to 3 crops of rice are harvested annually. The soil is about 1 meter deep.

[g] This has been cultivated intermittently.

[h] Representative of at least 10 square kilometers cultivated mostly in rice. Some sugar cane is grown.

[i] Orange soil.

TABLE III.—*Mechanical analyses of Batangas soils.*[a]

No.	Specimen.	Detritus not passing 1 mm. sieve.	Fine earth, water-free basis. Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.	Source.	Remarks.
	Cm.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
1	0–16	1.1	1.2	3.7	12.0	22.7	9.1	38.0	13.3	Santo Toribio, Lipa, Batangas.	Produces 150 cauas of sugar juice per hectare.
2	16–30	2.3	1.2	2.9	13.3	14.2	9.1	35.9	23.4	do	A composite sample of varying subsoils.
3	16–30	1.0	1.3	3.1	23.4	12.7	2.9	30.1	26.5	do	Sample when dark subsoil is excluded.
4	30–50	13.8	1.6	3.4	11.2	9.7	11.5	30.3	32.3	do	Subsoil to No. 1.
5	0–16	1.0	0.8	3.7	9.8	19.0	13.9	40.9	11.9	Marawoy, Lipa	Previously produced good crops of sugar cane, rice, and corn, but now uncultivated.
6	16–30	1.0	0.9	2.5	9.7	16.7	8.9	41.9	19.4	do	Subsoil to No. 5.
7	0–16	8.1	1.7	6.8	20.6	14.4	12.8	26.5	17.2	Sapak, Lipa	Composite sample of a number of fields.
8	16–30	12.0	1.2	4.1	21.5	10.1	13.4	25.6	24.1	do	This is underlain by volcanic tuff in certain sections.
9	0–16	1.2	1.2	4.2	16.5	9.1	25.5	32.8	10.7	Rosario	Rice field in low plain. Production considered good.
10	16–30	2.8	0.6	2.7	16.9	11.4	14.4	31.2	22.8	do	Subsoil to No. 9.
11	30–60	4.6	0.4	3.9	23.3	8.4	12.7	23.3	28.6	do	Clay substratum to No. 9.
12	0–16	3.8	1.6	3.8	17.9	9.6	19.2	26.3	21.6	Taysan	Rice field with hard volcanic tuff as subsoil.
13	0–16	2.2	1.2	2.8	7.2	11.7	10.4	36.1	30.6	do	At present, and for the last 2 years, cultivated in rice.
14	16–30	8.4	1.1	2.3	9.7	15.2	6.2	33.4	32.1	do	Subsoil to No. 13.
15	0–16	2.3	1.0	2.7	10.9	15.1	19.0	34.2	17.1	Matala, Ibaan	Brown loam with clayey subsoil.
16	16–30	5.4	0.5	1.9	20.0	14.8	6.3	29.3	27.2	do	Subsoil to No. 15.
17	0–16	1.2	1.6	5.0	8.9	13.6	22.8	32.6	15.5	Cabisang Bantasan, Ibaan.	Rice and corn are grown. Considered to produce fairly good crop.
18	16–30	1.8	1.3	2.9	11.8	30.0	3.1	32.4	18.5	do	Subsoil to No. 17.

20	0-16	3.5	1.6	3.9	21.8	17.2	3.1	31.4	21.1	Cagatan, Santo Niño, Batangas.	Dark clayey loam, considered to be very productive.
21	16-30	5.1	1.2	3.9	18.4	11.5	4.9	33.0	27.1	do	Light-colored and sticky clay. 1 meter from volcanic tuff.
22	0-16	2.4	0.8	2.7	21.6	18.3	11.5	28.9	16.2	Ilaya, Santo Niño, Batangas.	Produces decidedly inferior to No. 20. Subsoil volcanic tuff.
23	0-16	3.0	1.3	3.7	14.2	15.2	12.0	31.0	22.6	Haligue, Batangas	Rice field, said to produce good crop. District, mountainous.
24	16-30	4.4	1.0	2.4	8.1	11.0	9.6	37.1	30.8	do	Clay subsoil to No. 23. Volcanic tuff 1 meter below surface.
25	0-16	5.7	1.9	4.2	27.0	10.5	15.1	28.7	12.6	Buayahan, Batangas	Special type of soil found on moderately steep side of a hill.
26	16-30	11.5	2.5	7.0	36.6	15.5	13.3	18.6	6.5	do	Reddish clay. About 60 centimeters before volcanic tuff appears.
27	0-16	3.2	1.4	4.5	11.5	15.2	27.2	28.4	11.8	Libho, Batangas	Rice field.
28	16-30	3.3	0.7	2.9	9.5	12.6	23.0	32.4	18.9	do	Clayey, and from 1 to 3 meters deep.
29	0-16	3.9	0.1	0.6	16.6	31.7	17.7	26.0	7.3	Kalero, Batangas	Sugar-cane field of alluvial origin; has been cultivated for years, and produces well.
30	16-30	1.3	0.2	0.8	18.5	29.4	18.3	24.3	8.5	do	Subsoil to No. 29. Somewhat clayey.
31	0-16	6.3	1.1	3.5	31.4	21.0	11.3	25.4	6.3	At the foot of Mount Macolot, Cuenca.	Inclined to be gravelly on surface. Yields good crops in corn and rice.
32	16-30	3.2	2.0	5.1	31.6	21.1	7.5	22.0	10.7	do	Subsoil to No. 31.
33	0-16	5.0	3.4	7.4	21.4	19.6	9.5	28.1	10.6	Cuenca	Rice and corn field.
34	16-30	9.1	3.0	7.6	22.8	13.2	6.0	29.2	18.2	do	Subsoil to No. 33.
35	0-16	8.9	2.1	5.0	30.4	19.8	14.6	20.3	7.8	Bauan	Rice field, and considered to produce fairly well.
36	16-32	8.2	2.1	5.6	23.6	18.4	15.5	23.7	11.1	do	Somewhat darker than the surface.
37	0-16	6.2	2.9	5.2	13.3	15.5	19.2	31.8	12.1	Palengke, Batangas	Sugar cane used to be grown; production good. Rice and corn are now grown.
38	16-30	7.3	2.1	12.0	27.2	9.5	15.6	21.0	12.6	do	Subsoil to No. 37. Inclined to be sticky volcanic tuff about 60 centimeters from surface.
39	surface	3.1	0.9	3.0	28.6	16.6	8.8	26.2	15.9	Tubigan, Batangas	Black marshy soil. Very productive. Rice and forage are grown.

[a] For a description of the soils, see the footnotes to Table II.

TABLE III.—*Mechanical analyses of Batangas soils*—Continued.

No.	Specimen.	Detritus not passing 1 mm. sieve.	Fine earth, water-free basis. Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.	Source.	Remarks.
	Cm.	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
40	surface	15.4	7.0	22.9	30.4	12.2	7.5	12.0	8.0	Aplaya, Batangas	No crop grown. Salt is made in this place.
41	0–16	8.7	2.8	5.4	14.6	19.8	15.3	30.6	11.5	Kalansayan, San Jose	Tobacco was formerly grown, but now fields are planted in rice and corn. Production is good.
42	16–30	6.5	3.2	6.3	16.5	17.0	13.4	28.2	15.4	do	Subsoil to No. 41.
43	0–16	4.2	2.1	3.6	13.5	17.9	14.6	35.5	12.8	do	Produces good crops of tobacco, rice, or corn. Darker than No. 41.
44	16–30	4.6	2.3	4.6	13.6	16.9	12.4	35.1	15.1	do	Somewhat more clayey than surface.
45	0–10	8.9	4.2	8.6	21.7	20.2	10.3	23.9	11.1	Taal	2 kilometers from Taal, on line south 20° east.
46	10–30	3.8	4.4	10.2	24.5	13.8	15.1	20.3	11.7	do	Subsurface to No. 45.
47	At 150	11.4	2.7	5.6	24.7	16.7	25.6	18.8	5.9	do	Subsoil to No. 45.
48		10.2	1.7	6.4	17.9	15.7	11.4	28.3	18.1	Santo Tomas, Batangas.	150 meters north of station, on east side of railway.
49		2.8	1.3	5.9	18.3	17.8	11.2	26.8	18.7	do	The same general district as No. 49.

PANGASINAN

No general investigation of the soils of Pangasinan have been made except of the lands within the municipalities of Asingan, San Manuel, Urdaneta, and Villasis included in the proposed Ambalangan-Dalin irrigation system, although a few samples from other districts have been received and analyzed. As shown by the mechanical analysis of soils of the Ambalangan-Dalin district, the soil varies in texture from heavy tenacious clay loam to fine silt and sand or gravel. Mr. G. A. Graham, irrigation soil inspector of the Bureau of Public Works, describes these soils as follows:[38]

(*a*) *Heavy clay loam.*—This type of soil is to be found in the vicinity of Urdaneta and Villasis (see map, fig. 2). The surface and subsoil of this section of land is of the same composition and arrangement; a type of soil which has a maximum water capacity, and is capable of retaining a large percentage of it. These features make the soil especially suitable for rice culture.

(*b*) *Clay loam and sand.*—This type of soil is similar to that described above, but differs essentially in its water-holding capacity, which is due to the varying quantities of sand intermingled with the clay particles. This type of soil, while suitable to the growth of rice, will require more water than the former type.

(*c*) *Clay loam and gravel.*—A class of soil found around San Manuel; the proportion of clay and gravel in this soil is not very uniform. The soil between the Binalonon-San Miguel road and the Aborido ditch contains about 40 per cent clay, the remainder grading from cobble stones to fine sand. North of San Manuel and as far east as the barrio of San Antonio the soil is composed of about 30 per cent clay.

(*d*) *Fine silt and sand.*—By referring to the map it will be seen that a large percentage of the land is composed of fine silt and sand. Most of this soil has been formed by the overflow of the Agno River. This type of soil differs very materially from any that has been described. The surface is mainly of light loamy nature underlaid by a stratum of sand of various grades. On account of the porosity of the soil and the topography of the land, a large quantity of water will be needed for rice culture.

These soils were unquestionably all formed in the same way, but natural and artificial means have caused great variations in their physical properties and fertility. With reference to their physical properties as indicated by field observations, Mr. Graham reports with regard to classification and drainage as follows:

Class I.—This class includes all the lands within the vicinity of Villasis and Urdaneta. The soil is classified as first class for rice, as it has a large water-holding capacity and is of sufficient depth to give ample room

[38] An unpublished report made in 1910.

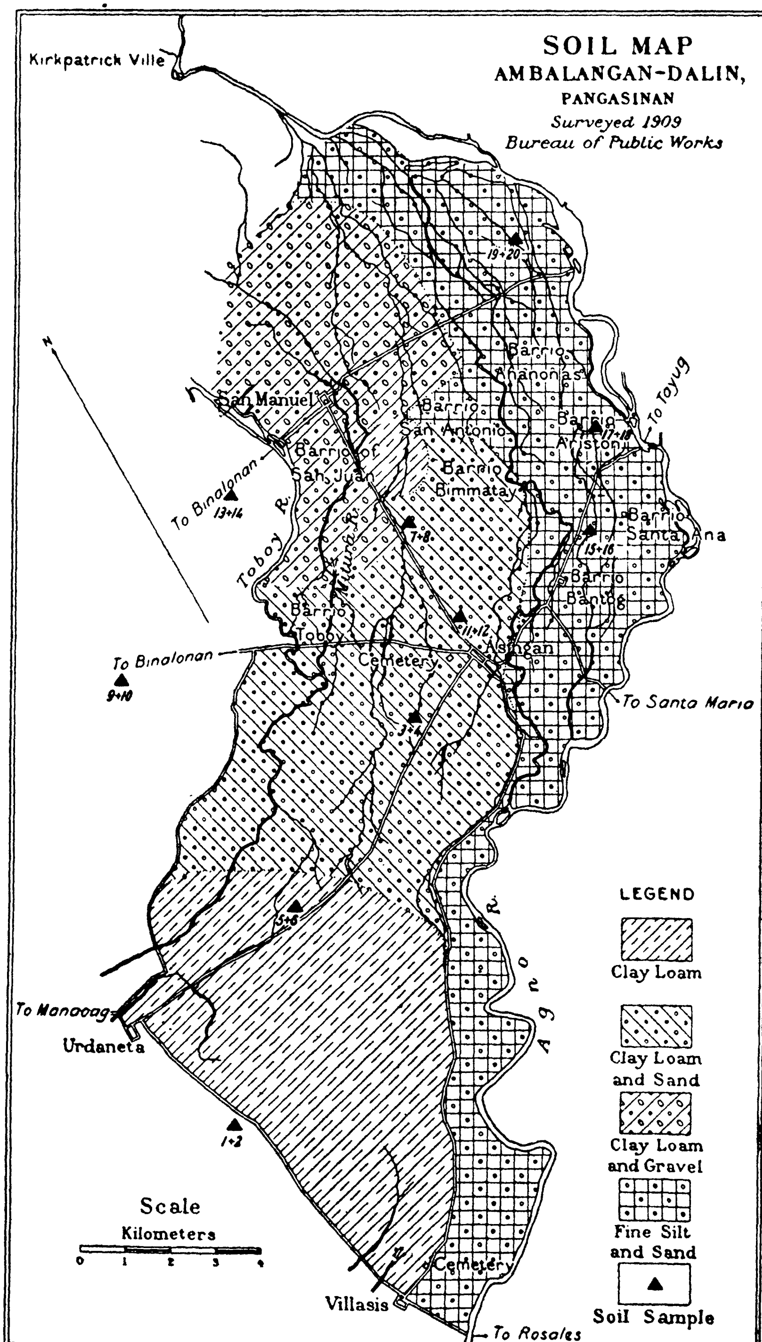

FIG. 2. Soil map of Ambalangan-Dalin, Pangasinan.

for root growth. These are two essential factors for proper rice culture. The soils of this class are remarkably uniform in character (see map). From data obtained during the high flood of July last, it is evident that a large percentage of fine silt is deposited on this land annually from the Agno River. The silt is beneficial as it improves the texture and supplies a certain percentage of plant food. The following analysis shows the percentage of fertilizing elements in river sediment. (See Appendix "I.")

Class II.—This class includes all the land within the municipality of Asingan. This soil has been classified as second class for rice, on account of its texture being open, which allows the escape of a certain percentage of free water. This land is similar to that of class I, but, on account of the sand in varying quantities, its water requirements will be greater.

Class III.—Here we find a type of soil which closely resembles that of class II, but differing essentially by the presence of a large percentage of gravel instead of sand. The topography of the land together with the openness of the soil admits of a large amount of seepage.

Class IV.—This class of soil includes all of the land in the northern part of the system and that adjacent to the river. The soil is very open, and allows the free water to percolate through it very readily. On account of this condition it is recommended that all of this type of soil north of the San Manuel-San Nicolas road, approximately 800 hectares, be not considered further for the irrigation of rice. The land, on the other hand, is best adapted to the cultivation of crops requiring less water and an open well-drained soil. Maguey, sugar cane, and corn are examples of such crops. The rate of seepage through the rest of this soil will not be so great as the land does not have as much slope and the water table is nearer the surface.

Drainage.—In the vicinity of San Manuel the topography is such that rice paddies have to be made small in order to distribute the water uniformly over the surface. On the other hand, the land around Urdaneta and Villasis is very low and flat, and the question of drainage is more important than that of irrigation on account of the close texture of the soil. The water from the rainfall percolates through the light open soil around San Manuel and passes through it unobstructed until it gets to within 500 meters of the Asingan-Binalonan road where it is impounded by a heavy stratum of clay loam. Here it is forced to the surface and is carried off in small ditches to be distributed again on the land near the Tonoy-Urdaneta road. The soil east of Asingan is of a light loamy character. Seepage water direct from the Agno River runs through it very readily, and the water finds an outlet on the land around Villasis.

In any irrigation project care must be taken to avoid surplus water, or the soil will not only become water-logged, but injurious alkali salts would accumulate. Portions of this district now suffer a great deal from lack of sufficient water, and if a water supply were available crops could be successfully grown during the dry season.

The chemical and mechanical analyses of Pangasinan soils are shown in Tables IV and V.

TABLE IV.—*Chemical analyses of Pangasinan soils.*[a]

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
1	0- 15	5.62	8.26	0.151	0.273	2.20	0.55	0.401	0.29	1.05	nonacid	100.0	North of Bacay, Urdaneta.	Typical of the district from Bacay to Urdaneta and Tagumasing to Pias.[b]
2	20-125	7.60	6.39	0.055	0.092	1.77	0.35	0.354	0.16	0.62	0.00375	100.0	____do	Subsoil to No. 1.[c]
3	0- 15	3.59	4.67	0.042	0.083	1.96	0.29	0.139	0.25	0.50	0.00375	100.0	Damampot, Asingan.	On the Asingan-Urdaneta road. This represents an area of 6 square kilometers.[d]
4	50-150	4.77	4.88	0.042	0.136	2.17	0.39	0.157	0.19	0.39	0.00750	100.0	____do	Subsoil to No. 3. Sand and gravel encountered at depth of 5 meters.
5	0- 25	5.38	7.01	0.142	0.134	1.54	0.39	0.201	0.48	0.83	0.00500	96.2	Near Bontog, Urdaneta.	Typical of an area of 100 hectares.[e]
7	0- 20	4.72	6.54	0.095	0.132	1.57	0.35	0.231	0.19	0.76	0.00375	99.2	San Juan, San Manuel.	Two hundred meters east of Asingan—San Manuel road.[f]
9	0- 20	7.08	7.69	0.174	0.085	1.60	0.19	0.110	0.25	0.77	0.00560	100.0	Bolo, Asingan.	Sample taken 100 meters south of municipal boundary monument separating Asingan from Binalonan on the Asingan-Binalonan road.[g]
11	0- 20	5.53	7.37	0.115	0.192	1.46	0.42	0.281	0.23	1.12	0.00425	100.0	Asingan.	Typical area of 200 hectares east of Asingan-San Manuel road.[h]
13	0- 20	10.03	5.28	0.116	0.191	1.42	0.54	0.326	0.33	0.88	0.00935	99.3	San Manuel.	On San Manuel-Binalonan road about 400 meters west of Toboy River.[i]
15	0- 20	4.21	5.74	0.078	0.171	2.75	0.50	0.222	0.23	0.74	0.00190	99.7	Asingan.	On the south side of Asingan-Tayug road midway between Bontog and Santa Ana.[j]
17	0- 15	3.18	4.10	0.033	0.128	2.39	0.38	0.180	0.36	0.35	0.00250	100.0	North of Santa Ana, Tayug.	Ten meters east of municipal monument between San Miguel and Tayug.[k]
19	0- 25	4.69	5.43	0.087	0.091	1.62	0.52	0.100	0.27	0.71	0.01565	99.5	Flores, San Manuel.	Taken from a small farm in the center of a large uniform district.[l]

21	0-30	2.77	2.13	------	0.099	1.55	0.27	0.268	0.89	------	------	100.0	Near Libsong, Lingayen.	One and one-half kilometers to the east of Lingayen, on the south side of the road.[m]
22	30-100	2.37	4.80	0.033	0.113	1.45	0.22	0.282	0.57	0.38	0.00312	100.0	do	Subsoil to No. 1.[n]

[a] Sampled after the method of Cox, *Phil. Journ. Sci., Sec. A* (1911), 6, by a representative of the Bureau of Lands.

[b] This area contains 18 square kilometers, and has been planted in rice for forty years, except in 1909 and 1910 when tobacco was grown. The crops are poor.

[c] No change to a depth of 1.75 meters. Residents claim that it is uniform to depth of 5 meters. A clay of this same appearance found near San Manuel is extensively used for making tiles. It burns deep red.

[d] Just past the last houses in Damampot barrio; 60 meters north and 45 meters west of broken brick culvert. For the last ten years rice and mongos have been raised. Previous to that period rice was exclusively grown. The 1911 crop of mongos was a complete failure, and that of rice 40 per cent below the average crop.

[e] This section has been cultivated for about forty years, always in rice, but since 1903 mongos have been grown as second crop. Water for irrigation is obtained from the Mitura River. Sandy substratum.

[f] It has been planted in rice for about forty years. Since 1902 mongos have been planted as a second crop biennally. Easily irrigated, and represents an area of 150 hectares. The substratum is somewhat intermixed with sand. Underlain with sandy loam.

[g] Typical of the district east of Binalonan with an area of 18 square kilometers. The district has always been planted in rice, only small sections being planted to mongos and tobacco, owing to wet subsurface. At a depth of about 75 centimeters, water is found over the entire area.

[h] Fifty meters east of monument marked "M" and "P," separating poblacion and barrio. No noticeable difference between surface and subsurface to a depth of 60 centimeters. The field has been exclusively planted in rice for about fifty years.

[i] Forty meters south of Bureau of Lands primary traverse monument "D. S." Owing to lack of water for irrigation, this district has not been planted since 1905. Previously mongos and corn were occasionally grown. Underlain with sand and gravel at depth of 1 meter.

[j] Center of test hole 70 meters south, 60 meters east of Bureau of Lands primary traverse "BJ." No appreciable difference to a depth of 1.25 meters, due to the fact that a large amount of silt is deposited during each rainy season. An alluvial deposit east of San Antonio, from 100 to 400 meters wide and about 6 kilometers long. It is about 2 meters lower than the surrounding region, and during the rainy season it is covered with water from 0.50 to 1.5 meters in depth. The immediate locality has been cultivated in rice for twenty-three years; previous to 1903 in rice alone. Since that time mongos have also been grown.

[k] The depth of from 25 to 37 centimeters consists of a strata of sand and of from 37 to 122 centimeters is loam below which is more sand. This district is subject to inundation from the Agno River. In 1908 and 1910 rice crops failed, and tobacco and corn have been planted as second crop on alternate years.

[l] Two thousand meters north of the center of Flores and 200 meters east of Bureau of Lands section traverse monument 1046. This land is under irrigation, and has produced good crops of rice, mongos, and eggplant. Tobacco of good quality is also produced. All mongo stalks and leaves have been plowed under, and good cultivation has been practiced. The land yields 40 per cent more than other farms in the surrounding district on account of exceptional care bestowed by the farmer. Sand and gravel underlie at about 2 meters.

[m] Cultivated in rice for many years and yields well. This soil is typical of the delta country. Surface water at about 1.5 meters.

[n] No characteristic difference between surface and subsoil.

TABLE V.—*Mechanical analyses of Pangasinan soils.*[a]

No.	Specimen.	Detritus not passing— 2 mm. sieve.	Detritus not passing— 1 mm. sieve.	Fine earth, water-free basis. Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.5 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
1	0– 15	0	0	0.6	3.2	10.6	11.0	31.7	26.2	6.7	North of Bacay, Urdaneta.	Typical of the district from Bacay to Urdaneta and Tagumasing to Pias.
2	20–125	0	0	0.4	0.8	10.7	11.1	25.1	40.4	11.5	do	Subsoil to No. 1.
3	0– 15	0	0	0.7	5.7	31.1	17.8	20.6	17.5	6.6	Dumanpot, Asingan.	On the Asingan-Urdaneta road. This represents an area of 6 square kilometers.
4	50–150	0	0	0.8	3.5	29.2	22.2	20.9	16.7	6.6	do	Subsoil to No. 3.
5	0– 25	0	3.8	9.3	14.6	14.8	7.5	10.0	32.7	11.1	Near Bontog, Urdaneta.	Typical of an area of 100 hectares.
6	25–100	0	7.9	1.0	3.5	16.9	23.7	28.9	21.6	4.4	do	Subsoil to No. 5.
7	0– 20	0	0.8	2.3	7.8	12.9	14.4	20.9	29.4	12.3	San Juan, San Manuel.	Two hundred meters east of Asingan-San Manuel road.
8	20– 75	0	0.5	1.5	5.9	12.3	12.2	26.8	27.9	13.4	do	Subsoil to No. 7.
9	0– 20	9	0	0.5	3.1	14.4	17.9	24.6	31.7	7.8	Bolo, Asingan	Sample taken 100 meters south of municipal boundary monument separating Asingan from Binalonan on the Asingan-Binalonan road.
10	20– 75	0	0	0.5	2.4	15.2	14.5	29.0	29.9	8.5	do	Subsoil to No. 9.
11	0– 20	0	0	0.8	4.0	11.7	14.8	22.8	37.6	8.3	Asingan	Typical area of 200 hectares east of Asingan-San Manuel road.
12	75–125	0	0	0.5	2.9	10.0	19.1	29.3	27.6	10.3	do	Subsoil to No. 11.
13	0– 20	0	0.7	1.2	4.3	25.5	26.9	21.2	17.1	3.8	San Manuel	On San Manuel-Binalonan road about 400 meters west of Toboy River.
14	20– 75	0	2.7	2.7	10.8	33.9	19.0	16.1	13.0	4.5	do	Subsoil to No. 13.

15	0- 20	0	0.3	0.3	6.0	41.0	37.7	15.6	7.0	2.4	Asingan	On the south side of Asingan-Tayug road midway between Bontog and Santa Ana.
16	at 135	0	1.1	0.6	1.3	40.6	25.6	15.9	12.5	3.5	do	Subsoil to No. 15.
17	0- 15	0	0	1.6	10.7	26.7	14.7	15.8	21.7	8.8	North of Santa Ana, Tayug.	Ten meters east of municipal monument between San Miguel and Tayug.
18	at 75	0	0	0.5	13.9	41.5	22.7	15.0	5.0	1.4	do	Subsoil to No. 17.
19	0- 25	0	0.5	0.4	2.9	11.1	12.3	25.8	34.7	12.8	Flores, San Manuel	Taken from a small farm in the center of a large uniform district.
20	30-110	0	0.6	1.8	8.5	21.2	12.1	16.2	26.8	13.4	do	Subsoil to No. 19.
21	0- 30	0	0	0	1.3	57.4	10.8	5.2	15.1	10.2	Near Libsong, Lingayen, Pangasinan.	One and one-half kilometers to the east of Lingayen, on the south side of the road.
22	30-100	0	0	0	2.0	75.1	6.9	4.2	6.6	5.2	do	Subsoil to No. 21.

[a] For a description of the soils, see the footnotes to Table IV.

MOUNTAIN PROVINCE

In Mountain Province, the temperatures are relatively lower than for the rest of the island, still rice (a staple diet) and many other cultivated crops of the lowlands grow luxuriantly. Also many varieties of vegetables and berries grown in the temperate zone thrive here. The agriculture is mostly carried on in irrigated mountain terraces. In certain wooded districts the soils are deficient in potash. When clearings are made, a sufficient amount of the ash from the burned products is concentrated on a given area to increase the potash to the desired

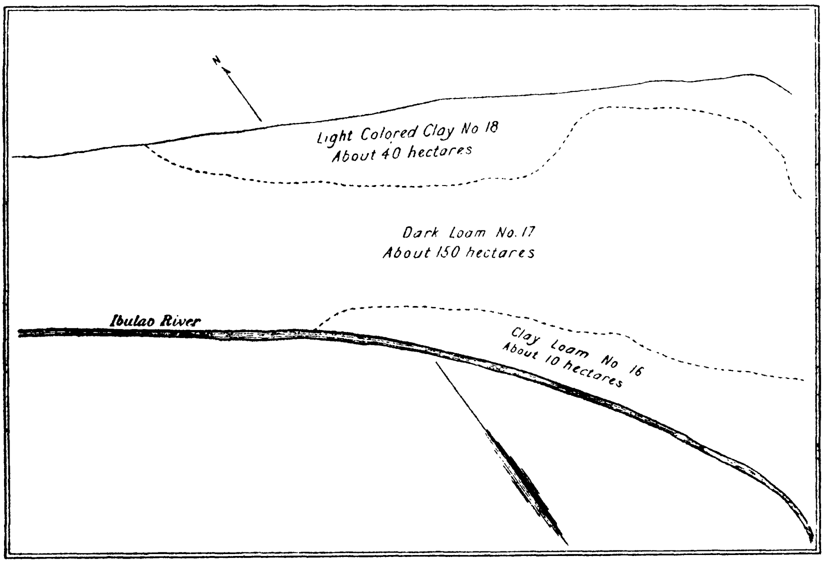

FIG. 3. Legaui Plateau, Ifugao, Mountain Province.

quantity. In spite of the great fertility of the soil in general as shown by the analyses, in time of drought there is serious rice shortage. All the available land where the inhabitants could lead water has been utilized. This has induced the Government to assist in opening new territory. For example, the Ifugaos have repeatedly tried to lead water to the unused Legaui Plateau without success. The difficulties were too great until the Government furnished dynamite with which to blast out the rock. With the building of an irrigation ditch to, and a supply of water available for, the Legaui Plateau, 200 hectares of tillable rice land have been added to the province. A rough diagram of this region is shown in fig. 3.

The Nos. in fig. 3 refer to those given to the soils in Table VI.

Chemical and mechanical analyses of soils from Mountain Province are given in Tables VI and VII.

CAGAYAN

The soils of the Cagayan Valley are generally considered to be exceedingly fertile, and are used for the cultivation of corn, tobacco, etc. Much of the district is inundated from time to time, and the composition of the soils is continually changing. The general characteristics may be indicated by the chemical and mechanical analyses given in Tables VIII and IX.

LAGUNA AND TAYABAS

Laguna and Tayabas Provinces have been found especially suited to the production of coconuts, and the soil samples, the analyses of which are given in Tables X and XI, have been taken in an effort to give information with regard to some of the controlling factors of the ideal soil for this crop.

PAMPANGA, BATAAN, TARLAC, AND BULACAN

Miscellaneous chemical and mechanical analyses of soils from Pampanga, Bataan, Tarlac, and Bulacan Provinces are given in Tables XII and XIII.

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TABLE VI.—*Chemical analyses of Mountain Province soils.*

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O).	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
1	0–30	7.03	9.52	0.197	0.125	2.45	0.87	1.113	0.38	1.43	0.00625	93.1	Bokod	Rice paddies in the vicinity of the presidencia.
2	0–30	5.61	11.12	0.193	0.091	0.34	0.31	0.628	0.31	1.00		94.7	Daklan	Coffee grove south of the presidencia.
3	0–30	8.33	12.77	0.183	0.078	0.09	0.18	0.642	0.34	2.12		100.0	do	Coffee grove adjacent to the presidencia.
4	0–30	9.53	13.99	0.288	0.231	0.19	0.13	0.473	0.24	2.36		99.0	do	Rice paddies in the vicinity of the presidencia.
5	0–30	7.79	9.45	0.180	0.299	1.22	0.42	0.432	0.45	2.51		81.4	Updas	Coffee soil.
6	0–30	7.99	10.57	0.217	0.285	1.76	0.93	1.369	0.43	2.34	0.00875	73.1	Bakung	Coffee soil, composite sample.[a]
7	0–30	7.97	11.55	0.237	0.083	1.51	0.43	0.082	0.60	2.85	0.00812	97.3	Lutab	Rice paddies below and south of the presidencia.
8	0–30	6.90	9.55	0.177	0.087	1.12	0.32	0.551	0.50	1.51		92.1	do	First group of terraced rice paddies to the north.
9	0–30	6.68	10.00	0.239	0.066	0.76	0.88	0.508	0.72	1.65		96.3	Cabayan	Second group of terraced rice paddies north of Lutab.
10	0–30	6.86	11.30	0.237	0.112	1.69	0.73	0.291	0.34	1.57		98.1	Casarang	From terraced rice paddies.
11	0–30	6.50	11.24	0.255	0.104	1.86	0.79	0.299	0.45	1.82	0.00875	88.7	do	First group of terraced paddies to the north.
12	0–30	6.68	10.76	0.208	0.079	1.71	0.69	0.224	0.21	1.31		98.3	Lower Ahin Valley	Composite sample from rice terraces.
13	0–30	8.28	12.85	0.275	0.087	1.32	0.63	0.451	0.19	1.21		99.0	Sapao Valley	About 3 kilometers toward Banaue from Sapao.
14	0–30	8.58	11.16	0.212	0.234	2.84	0.41	0.501	0.35	0.69		98.4	Banaue	Rice field.
15	0–30	10.60	10.87	0.175	0.048	0.69	0.30	0.371	0.27	0.92		99.1	Amganad Valley	First valley toward Quiangan from Banaue.[b]
16	0–30	10.55	10.27	0.162	0.049	0.64	0.26	0.087	0.17	1.25		92.8	Legaui Plateau	Virgin land, black loam.
17	0–30	10.38	15.47	0.328	0.202	0.92	0.60	0.208	0.18	3.83		100.0	do	Virgin land, stiff black soil.
18	0–30	11.34	9.14	0.116	0.087	1.62	0.43	0.195	0.12	0.47		100.0	do	Virgin land, clay.

19	0- 30	10.69	9.80	0.098	0.034	0.99	0.37	0.429	0.21	0.69	----------	98.7	Quiangan	Rice paddy in vicinity.
20	0- 30	10.54	11.97	0.288	0.368	1.28	0.44	0.794	0.35	1.98	0.01187	95.8	do	Coffee land, a mixture of composite samples from Ambabag and Pinduagan.
21	0- 30	11.52	8.96	0.162	0.256	1.18	0.36	0.582	0.22	1.00	----------	97.2	Lamut Valley	Rice paddy in vicinity of Polo.
22	0- 30	13.40	19.69	0.406	0.094	2.13	0.48	0.410	0.21	2.54	----------	81.3	Auwa Valley	Camote field.[c]
23	0- 30	4.78	7.62	0.272	0.116	2.43	0.43	0.426	0.17	2.05	0.00750	56.0	Upper Mamatra River.	Composite sample from the rice paddy terraces.[d]
24	0- 30	6.46	11.74	0.321	0.072	1.68	0.63	0.169	0.19	2.15	----------	61.4	Upper Ahin Valley	From terraces opposite the Ahin River spring from which salt is being produced.
25	0- 30	11.02	27.36	0.447	0.079	2.99	0.85	0.074	0.19	5.67	----------	33.6	Auwa	Pine forest soil near the top of Polis range.[e]
26	0- 30	9.70	23.62	0.322	0.503	0.48	0.45	0.167	0.18	5.27	0.02625	57.4	Mount Pulog	On a 25°-30° grassy pine slope. Altitude 1,700 meters.[f]
27	0- 10	10.88	38.11	0.787	0.152	0.73	0.46	0.101	0.21	8.97	----------	74.3	do	From valley on mountain top. Collected January, 1908.
28	below 30	9.42	25.58	0.513	0.058	0.88	0.61	0.065	0.20	3.62	----------	89.6	do	From grassy top. Altitude 2,890 meters. Collected January, 1909.
29	0- 30	10.89	20.79	0.320	0.108	0.24	0.16	0.063	0.22	4.51	----------	-------	Haight's flat	Surface.
30	30- 90	2.96	3.69	0.043	0.049	0.84	0.17	0.125	0.27	0.45	0.00125	-------	do	Light brown.
31	90-117	4.88	24.50	0.479	0.128	0.10	0.17	0.084	0.19	13.30	----------	-------	do	Black.
32	117 down	2.90	3.13	0.082	0.101	0.11	0.09	0.138	0.15	0.86	----------	-------	do	Light yellow.
33	----------	22.13	55.61	0.752	0.098	0.10	0.10	0.065	0.10	17.12	----------	-------	Haight's bog	A newly cultivated field.[g]
34	----------	11.57	25.81	0.739	0.191	0.23	0.24	0.058	0.21	9.56	0.00937	-------	Haight's forest	A new clearing.[h]

[a] Five representative places and five variations.

[b] One portion was taken from just below Auwa camarin, another halfway between Auwa and Ahandun, and a third just below Hinduan.

[c] This valley was originally covered with hills, but they were gradually eroded year by year and carried away by streams until now the bottom of the valley is practically flat and is cultivated in rice.

[d] Composite sample representing a virgin tropical forest soil.

[e] Composite sample was taken 16 kilometers below where the trail leaves the Dundu or upper Mamatza River for the village of Dungu. Black soil is the most abundant, while the red soil is found in limited areas.

[f] Collected January, 1908, by F. W. Foxworthy.

[g] One could thrust a bar downward into this soil for at least 2 meters.

[h] Representative of the nonconiferous forests of Benguet.

TABLE VII.—*Mechanical analyses of Mountain Province soils.*[a]

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1-0.5 mm.	Medium sand 0.5-0.25 mm.	Fine sand 0.25-0.10 mm.	Very fine sand 0.10-0.05 mm.	Silt 0.05-0.01 mm.	Very fine silt 0.010-0.002 mm.	Clay less than 0.002 mm.		
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
1	0-30	0.4	6.5	3.9	6.4	19.5	16.3	15.4	25.5	13.0	Bokod	Rice paddies in the vicinity of presidencia.
2	0-30	1.9	3.4	1.0	6.8	16.4	20.3	6.4	33.8	15.3	Daklan	Coffee grove south of the presidencia.
3	0-30	0	0	1.2	4.0	8.1	7.9	8.9	42.1	27.8	do	Coffee grove adjacent to the presidencia.
4	0-30	0.7	0.3	4.0	10.7	24.5	10.6	12.9	27.9	9.4	do	Rice paddies in the vicinity of the presidencia.
5	0-30	14.8	3.8	3.5	5.7	16.4	15.1	9.7	31.3	18.3	Updas	Coffee soil.
6	0-30	15.5	11.4	4.0	2.3	27.7	15.3	11.3	27.0	12.4	Bakung	Coffee soil, composite sample.
7	0-30	1.1	1.6	3.3	6.5	19.5	16.3	16.5	26.7	11.2	Lutab	Rice paddies below and south of the presidencia.
8	0-30	6.1	1.8	4.1	7.2	18.7	13.4	13.6	26.4	16.6	do	First group of terraced rice paddies to the north.
9	0-30	1.8	1.9	4.7	8.5	17.1	11.9	14.3	31.0	12.5	Cabayan	Second group of terraced rice paddies north of Lutab.
10	0-30	0.4	1.5	2.6	4.1	15.8	18.7	20.8	28.5	9.5	Casarang	From terraced rice paddies.
11	0-30	4.2	7.1	2.8	0.7	24.7	16.8	17.8	27.4	9.8	do	First group of terraced paddies to the north.
12	0-30	1.2	0.5	3.5	5.4	18.7	19.9	15.3	29.2	8.0	Lower Ahin Valley	Composite sample from rice terraces.
13	0-30	0.6	0.4	3.2	5.9	22.8	13.0	13.9	31.1	10.1	Sapao Valley	About 3 kilometers toward Banaue from Sapao.
14	0-30	1.5	0.1	7.7	10.1	25.1	14.4	15.0	21.7	6.0	Banaue	Rice field.
15	0-30	0	0.1	3.9	8.3	31.8	17.2	14.2	18.6	6.0	Amganad Valley	First valley toward Quiangan from Banaue.

16	0-30	3.9	3.3	3.6	10.8	19.2	8.1	7.0	21.8	30.0	Legaui Plateau	Virgin land, black loam.
17	0-30	0	0	6.8	14.3	45.9	12.0	3.3	11.3	6.4	do	Virgin land, stiff black soil.
18	0-30	0	0	2.3	6.6	16.7	9.9	6.2	26.4	31.9	do	Virgin land, clay.
19	0-30	0.7	0.6	6.7	12.2	21.5	13.8	12.9	22.2	10.7	Quiangan	Rice paddy in vicinity.
20	0-30	0	4.2	5.6	10.6	25.2	13.6	12.1	21.8	11.1	do	Coffee land a mixture of composite samples from Ambabag and Pinduagan.
21	0-30	1.2	1.6	3.4	10.2	25.5	16.6	11.4	21.2	11.7	Lamut Valley	Rice paddy in vicinity of Polo.
22	0-30	13.6	1.5	11.0	16.3	25.9	10.9	7.4	19.6	8.9	Auwa Valley	Camote field.
23	0-30	40.9	3.1	3.2	8.0	19.2	15.6	12.8	32.2	9.0	Upper Mamatra River	Composite sample from the rice-paddy terraces.
24	0-30	38.4	0.1	4.5	8.1	17.8	16.5	11.7	32.5	8.9	Upper Ahin Valley	From terraces opposite the Ahin River spring from which salt is being produced.
25	0-30	47.9	18.5	13.2	19.2	31.8	13.4	8.1	9.3	5.0	Auwa	Pine forest soil near the top of Polis range.
26	0-30	41.3	1.5	6.4	10.8	30.5	17.4	9.5	16.3	9.1	Mount Pulog	On a 25°-30° grassy pine slope. Altitude, 1,706 meters.
27	0-10	13.5	12.2	19.1	26.8	19.7	13.6	3.9	8.6	8.1	do	From valley on mountain top. Collected January, 1908.
28	below 30	8.2	2.2	15.4	27.6	27.3	8.25	2.8	8.7	10.0	do	From grassy top. Altitude, 2,890 meters. Collected January, 1909.
29	0-30			5.0	14.6	49.4	15.1	5.7	5.9	4.3	Haight's flat	Surface.
30	30-90			13.6	30.7	31.7	15.1	1.4	4.9	2.6	do	Light brown.
31	90-117			4.7	24.4	40.7	13.5	5.9	4.5	6.3	do	Black.
32	117 down			6.0	15.0	12.5	12.1	7.0	26.8	20.6	do	Light yellow.
33				24.6	25.1	5.2	15.5	6.3	9.9	13.4	Haight's bog	A newly cultivated field.
34				5.3	22.6	28.7	15.1	8.5	8.6	11.2	Haight's forest	A new clearing.

[a] For a description of the soils, see the footnotes to Table VI.

TABLE VIII.—*Chemical analyses of Cagayan soils.*

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
1	0- 30	9.99	11.07	0.290	0.166	0.66	0.44	0.226	0.08	2.34	100.0	Marahuirahui	Tobacco field in a pocket surrounded by hills.[a]
2	at 85	9.43	10.38	0.163	0.106	0.68	0.36	0.198	0.05	1.18	100.0	do	Subsoil to No. 1.
3	0- 30	8.96	15.47	0.342	0.205	0.67	0.27	0.260	0.16	2.34	100.0	do	Corn field on the hillside. *Caiñgin* land near No. 1.
4	at 100	10.73	12.08	0.117	0.106	0.49	0.37	0.236	0.10	0.87	100.0	do	Subsoil to No. 3.
5	0- 30	10.07	8.48	0.138	0.159	1.98	0.24	0.325	0.23	0.95	100.0	San Luis	Alluvial tobacco field somewhat on the hillside.
6												do	Subsoil to No. 5.
7	0- 30	6.45	8.62	0.132	0.139	2.34	0.41	0.219	0.18	0.78	100.0	do	Low alluvial deposit near the river where tobacco is cultivated.[b]
8	at 100	5.58	9.24	0.136	0.165	1.92	0.20	0.213	0.33	0.87	100.0	do	Subsoil to No. 7.
9	0- 30	4.59	7.46	0.073	0.074	1.18	0.06	0.123	0.20	0.58	100.0	San Antonio No. 23, District Nuevo.	Tobacco field never inundated except once in 1908.
10	at 100	4.56	7.22	0.083	0.106	1.38	0.31	0.114	0.22	0.57	100.0	do	Subsoil to No. 9.
11	0- 30	4.76	8.14	0.100	0.121	1.12	0.15	0.118	0.23	0.81	100.0	San Antonio, District No. 15	Alluvial tobacco field.[c]
12	at 100	5.39	8.43	0.101	0.111	1.26	0.22	0.083	0.25	0.81	100.0	do	Subsoil to No. 11.
13	0- 30	8.11	7.64	0.142	0.308	1.89	0.26	0.611	0.29	0.89	100.0	Santa Isabel, Sifu district	Tobacco field not subject to inundation.[d]
14	at 100	9.94	8.36	0.102	0.231	1.72	0.18	0.629	0.17	0.71	100.0	do	Subsoil to No. 13.

[a] Of alluvial origin and subject to annual inundation.
[b] The tobacco grown is very poor, probably due to imperfect cultural methods.
[c] Subject to annual inundation. The cultivation is very shallow, and the tobacco is very poor.
[d] Cultivated in tobacco for fourteen years. Very dry, and situated on a high elevation.

TABLE IX.—*Mechanical analyses of Cagayan soils.*[a]

No.	Specimen.	Detritus not passing— 2 mm. sieve.	Detritus not passing— 1 mm. sieve.	Fine earth, water-free basis. Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002	Clay less than 0.002 mm.	Source.	Remarks.
	Cm.			*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
1	0–30	nil	nil	0.3	4.5	10.8	16.2	8.8	41.6	17.8	Marahuirahui	Tobacco field in a pocket surrounded by hills.[a]
2	at 85	nil	nil	0.4	3.7	7.5	14.4	10.1	36.5	27.4	do	Subsoil to No. 1.
3	0–30	nil	nil	2.1	8.6	16.8	12.1	9.7	29.4	21.3	do	Corn field on the hillside. Caiñgin land near No. 1.
4	at 100	nil	nil	1.9	4.2	6.9	8.1	9.3	30.1	39.5	do	Subsoil to No. 3.
5	0–30	nil	nil	0	0.7	20.9	29.1	15.1	26.8	7.4	San Luis	Alluvial tobacco field somewhat on the hillside.
6	subsoil	nii	nil	0.2	3.8	11.0	30.6	22.4	25.1	6.9	do	Subsoil to No. 5.
7	0–30	nil	nil	0	1.5	23.6	36.7	12.0	21.0	5.2	do	Low alluvial deposit near the river where tobacco is cultivated.[b]
8	at 100	nil	nil	0	1.1	18.9	37.2	13.4	23.4	6.0	do	Subsoil to No. 7.
9	0–30	nil	nil	0	0.4	26.8	34.6	12.7	19.7	5.8	San Antonio No. 23, District Nuevo.	Tobacco field never inundated except once in 1908.
10	at 100	nil	nil	0	0.4	18.7	34.0	16.7	23.9	6.3	do	Subsoil to No. 9.
11	0–30	nil	nil	0	0.5	8.3	34.0	16.1	33.7	7.4	San Antonio, District No. 15.	Alluvial tobacco field.[c]
12	at 100	nil	nil	0	0.6	7.4	20.7	1.7	59.4	10.2	do	Subsoil to No. 11.
13	0–30	------	------	0	3.1	16.3	23.1	20.2	28.0	9.3	Santa Isabel, Sifu district.	Tobacco field not subject to inundation.[d]
14	at 100	nil	nil	0	3.3	13.0	9.8	16.2	41.0	16.7	do	Subsoil to No. 13.

[a] Of alluvial origin and subject to annual inundation.
[b] The tobacco grown is very poor, probably due to imperfect cultural methods.
[c] Subject to annual inundation. The cultivation is very shallow, and the tobacco is very poor.
[d] Cultivated in tobacco for fourteen years. Very dry, and situated on a high elevation.

TABLE IX.—*Mechanical analyses of Cagayan soils*—Continued.

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002	Clay less than 0.002 mm.		
	Cm.			*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
15	surface	nil	nil	2.9	6.4	26.0	21.5	6.5	19.2	16.5	Santa 34 Pacadon, Babayoan.	Maguey field situated on rolling hills.
16	subsoil	nil	nil	2.5	5.1	16.3	17.8	7.7	18.9	31.7	do	Subsoil to No. 15.
17	surface	nil	nil	1.1	9.1	31.5	20.5	15.1	17.8	4.9	Dumon River, Pulagao	Corn field, but on previous year planted to tobacco.
18	subsoil	nil	nil	0.1	4.5	15.5	24.9	16.5	29.5	9.0	do	Subsoil to No. 17.
19	surface	nil	nil	0	0.6	29.2	42.1	13.0	11.9	3.2	Cumao on Dumon River	Planted to tobacco.
20	subsoil	nil	nil	0	1.3	11.4	28.9	23.0	30.8	4.6	do	Subsoil to No. 19.
21	surface	nil	nil	2.6	8.9	37.1	22.5	11.4	13.2	4.3	Catubug	Tobacco field.
22	subsoil	nil	nil	0	1.6	17.1	30.9	22.6	22.1	5.7	do	Subsoil to No. 21.
23	surface	nil	nil	3.3	9.5	32.8	23.5	12.3	14.0	4.6	Ilame	Tobacco field.
24	subsoil	nil	nil	0	1.6	16.6	29.0	23.8	22.8	6.2	do	Subsoil to No. 23.
25	surface	nil	nil	0.4	2.6	14.0	31.8	21.8	24.0	5.4	Gaddangao	Corn field.
26	subsoil	nil	nil	0.3	1.8	12.9	34.1	23.2	21.9	5.8	do	Subsoil to No. 25.

TABLE X.—*Chemical analyses of coconut soils.*[a]

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
1	0–15	8.84	12.24	0.143	0.128	0.63	0.44	0.485	0.66	0.98	0.01310	100	Magdalena, Laguna.	From a coconut grove about 0.5 kilometer north of the railroad station.[b]
2														
3														
4	0–30	3.51	6.23	0.105	0.202	1.27	0.26	0.341	1.19	0.96	0.00315	100	Pagsanjan, Laguna.	From a coconut grove 0.5 kilometer on the north side of the road from the town.[c]
5														
6	0–30	3.39	5.08	0.088	0.236	1.85	0.09	0.149	0.70	0.79	0.00250	100	Santa Cruz, Laguna.	From a coconut grove 1 kilometer from the town on the north side of the Santa Cruz-Pagsanjan road.[d]
7														
8	0–30	3.82	5.32	0.104	0.281	2.92	0.32	0.211	0.86	0.68	0.00315	100	San Pablo, Laguna	From a coconut grove northwest of the railroad station.[e]
9														
10	0–30	4.80	7.36	0.127	0.324	2.49	0.42	0.239	0.79	1.73	0.00187	100	Tiaong, Tayabas	From a coconut grove 1 kilometer from the railroad station on the Tiaong road.[f]

[a] Sampled after the method of Cox, *This Journal, Sec. A* (1911), **6**, 326.

[b] The trees are about 25 years old, and produce an average of 50 nuts each per year. Parts of the field are underlain with semidecomposed volcanic tuff, while at other places the subsoil is clayey.

[c] The trees are about 40 years old, and produce an average of 50 nuts each per year. The soil is deep, being 1.5 to 2 meters before rock is encountered. The subsoil is slightly more reddish and plastic than the surface.

[d] It is said that some individual trees in this grove produce 40 nuts in one gathering or about 160 nuts a year. The trees average 80 nuts each per year. The chemical composition and physical texture of the soil seem to be ideal for coconut growing. The surface is loose and mellow. The subsoil is similar to the surface soil, but the amount of sand increases with the depth. There is no appreciable change in 2 meters.

[e] The soil is loose and mellow, and produces well. The surface and subsoil are practically the same in appearance. Volcanic tuff is encountered at a depth of 2 meters.

[f] The trees vary from 15 to 20 years, and are estimated to produce an average of 100 nuts each per year. Individual trees are said to produce as many as 200 nuts annually.

TABLE X.—*Chemical analyses of coconut soils*—Continued.

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		*P. ct.*		
11														
12	at 200	0.65	0.86	0.019	0.181	3.46	0.23	0.217	1.28				Tiaong, Tayabas	From the bank of a stream near sample No. 10. [a]
13	0- 25	6.66	9.05	0.135	0.138	0.68	0.31	0.249	0.19	1.39	0.00437	100	Masing, Candelaria, Tayabas.	1 kilometer from Candelaria, on the south side of the Tiaong road. [b]
14														
15	0- 20	2.03	5.53	0.140	0.376	1.64	0.16	0.208	0.68	1.59	0.00375	100	Manguilay, Candelaria, Tayabas.	4 kilometers on the north side of the Candelaria-Saryaya road. [c]
16	0- 30	1.64	3.87	0.086	0.286	1.74	0.11	0.157	0.78	0.70	0.00315		Kanda, Saryaya, Tayabas.	From a coconut grove. [d]
17														
18	0- 30	3.55	4.82	0.095	0.206	1.40	0.22	0.169	0.43	0.71	0.0025	100	Lucena, Tayabas	From a coconut grove about 0.5 kilometer from the river, on the bank opposite the town. [e]
19	0- 30	3.46	6.48	0.120	0.191	1.65	0.30	0.195	0.39	1.16	nonacid	100	do	From a poorer coconut grove which produces from 70 to 80 nuts per tree annually. [f]
20	0- 20	8.38	13.23	0.236	0.032	0.44	0.57	0.275	0.85	1.16	0.00975	100	do	From an adjacent field covered with grass. [g]

[a] This soil in place has the appearance of rock, but easily crumbles when struck. The depth of the layer is about 5 meters.

[b] A very poor type of coconut soil. The coconut trees look stunted, and bear few and small nuts. The average annual crop is from 24 to 28 nuts per tree. The soil is clayey, especially the subsoil, which probably explains the poor tree growth. The region is underlain with volcanic tuff, at a depth of about 1.5 meters.

[c] The trees produce from 80 to 100 nuts each per year. Below 20 centimeters, the soil is intermixed with stones, but the fine constituents of the subsoil are of the same character as the surface.

[d] The trees vary from 25 to 30 years in age, and are said to average 120 nuts each annually. The soil is loose and mellow, and is at least 2 meters deep. The soil texture appears satisfactory for coconuts.

[e] The trees are vigorous, and are estimated to produce about 100 nuts per tree annually. Both surface and subsoil are loose and mellow.

[f] Surface and subsoil are loose and mellow, and extend to a depth of 1.5 meters. A good coconut soil.

[g] This is given for comparative purposes. It is said to be not adapted to coconuts, and will not grow a good crop of corn.

TABLE XI.—*Mechanical analyses of coconut soils.*[a]

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.		
	Cm.			*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
1	0– 15	nil	nil	0.8	3.9	9.0	11.1	12.2	35.5	27.5	Magdalena	From a coconut grove about 0.5 kilometer north of the railroad station.
2	15–100	nil	nil	1.1	3.1	5.3	10.2	14.8	34.1	31.4		Subsoil to No. 1. From the portion of the field containing the most gravel.
3	15– 80	nil	nil	0.5	1.9	6.6	9.0	9.2	34.0	38.8		Subsoil to No. 1. From the portion of the field containing the most clay.
4	0– 30	nil	nil	2.5	4.9	30.5	18.6	10.7	18.7	14.1	Pagsanjan, Laguna.	From a coconut grove 0.5 kilometer on the north side of the road from the town.
5	30–100	nil	nil	0.5	2.5	23.7	21.2	17.8	21.9	12.4	do	Subsoil to No. 4.
6	0– 30	nil	nil	1.3	8.8	32.7	18.3	9.0	17.1	12.8	Santa Cruz, Laguna.	From a coconut grove one kilometer from the town on the north side of the Santa Cruz-Pagsanjan road.
7	30–100	nil	nil	3.5	14.8	36.5	14.2	10.3	12.8	7.9	do	Subsoil to No. 6.
8	0– 30	nil	nil	6.1	10.5	19.5	15.7	14.3	23.4	10.5	San Pablo, Laguna	From a coconut grove northwest of the railroad station.
9	30–100	nil	nil	6.4	12.8	17.7	11.4	14.6	24.2	12.9	do	Subsoil to No. 8.
10	0– 30	nil	nil	1.0	2.7	10.4	15.9	24.1	34.5	11.4	Tiaong, Tayabas	From a coconut grove 1 kilometer from the railroad station, on the Tiaong road.
11	30–100	nil	nil	0.5	2.8	12.4	15.4	27.5	32.8	8.6	do	Subsoil to No. 10.
12	at 200	nil	nil	24.0	37.6	18.1	5.3	6.8	6.2	2.0	do	From the bank of the stream near sample No. 10.
13	0– 25	nil	nil	1.0	3.9	11.3	10.9	22.1	33.3	17.5	Masing, Candelaria, Tayabas.	1 kilometer from Candelaria, on the south side of the Tiaong road.

[a] For a description of the soils, see the footnotes to Table X.

TABLE XI.—*Mechanical analyses of coconut soils*—Continued.

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1-0.5 mm.	Medium sand 0.5-0.25 mm.	Fine sand 0.25-0.10 mm.	Very fine sand 0.10-0.05 mm.	Silt 0.05-0.01 mm.	Very fine silt 0.010-0.002 mm.	Clay less than 0.002 mm.		
	Cm.			*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*		
14	25- 80	nil	nil	0.7	2.4	12.5	10.3	17.6	30.4	26.1	Masing, Candelaria, Tayabas.	Subsoil to No. 13.
15	0- 20	nil	nil	11.5	23.1	28.1	11.1	6.2	12.1	7.9	Manguilay, Candelaria, Tayabas.	4 kilometers on the north side of the Candelaria-Saryaya road.
16	0- 30	nil	nil	8.8	28.1	38.1	9.8	4.4	5.7	5.1	Kanda, Saryaya, Tayabas.	From a coconut grove.
17	30-100	nil	nil	6.4	17.5	40.7	16.9	8.0	5.9	4.6	do	Subsoil to No. 16.
18	0- 30	nil	nil	4.2	17.3	43.2	8.9	6.1	11.1	9.2	Lucena, Tayabas	From a coconut grove about 0.5 kilometer from the river, on the bank opposite the town.
19	0- 30	nil	nil	0.6	9.0	39.6	12.5	9.6	18.6	10.1	do	From a poorer coconut grove, which produces from 70 to 80 nuts per tree annually.
20	0- 20	nil	nil	1.9	3.9	8.7	10.7	15.7	27.6	31.5	do	From an adjacent field covered with grass.

TABLE XII.—*Chemical analyses of miscellaneous Luzon soils.*

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
1	0- 25	4.91	6.39	0.106	0.467	1.02	-------	0.443	-------	-------	-------	100	San Fernando, Pampanga.	Sugar-cane field. Below a depth of 25 centimeters this is underlain by a yellow clay subsoil. At about 1 meter from the surface a fine yellow sand substratum is encountered.
2	25- 50	6.59	6.60	0.075	0.362	1.13	-------	0.194	-------	-------	-------	100	do	Subsoil to No. 1.
3	0- 25	3.20	6.25	0.111	0.113	0.10	-------	0.063	-------	-------	-------	100	Camp Stotsenberg, Pampanga.	From near-by foothills. Underlain by yellowish clay at about 25 centimeters. It is a loam of residual origin adjacent to which are alluvial deposits consisting principally of coarse sand.
4	25- 50	4.14	6.33	0.077	0.134	0.23	-------	0.060	-------	-------	-------	100	do	Subsoil to No. 3.
5	0- 30	1.25	3.96	0.073	0.127	0.55	-------	0.095	-------	-------	-------	92.7	Near Magalang, Pampanga.	From sugar land representing a type of soil generally found in the valley of that section of Pampanga. Sandy for a depth of at least several meters.
6	30-150	0.73	1.77	0.054	0.126	0.50	-------	0.112	-------	-------	-------	90.6	do	Subsoil to No. 5.
7	0- 30	3.34	4.74	0.087	0.098	0.62	0.13	0.144	0.21	0.71	0.0062	100	Florida Blanca, Pampanga.	Hacienda Bernia, cultivated in sugar cane.
8	0- 30	5.21	6.24	0.131	0.156	1.08	0.22	0.153	0.31	0.94	0.0054	100	Dinalupihan, Bataan.	1 kilometer from Casa-Hacienda on Gutat road. Cultivated in sugar cane.
9	0- 30	5.84	6.17	0.136	0.143	0.91	0.17	0.124	0.26	1.08	0.0109	100	do	0.5 kilometer from Casa-Hacienda. Sugar land.
10	0- 30	3.49	4.40	0.090	0.124	0.81	0.15	0.146	0.34	0.66	0.0070	100	Between Gutat and Dinalupihan, Bataan.	From Hacienda-Velez. Cultivated in sugar cane.

TABLE XII.—*Chemical analyses of miscellaneous Luzon soils*—Continued.

No.	Specimen of soil.	Moisture (H_2O).	Loss on ignition.	Nitrogen (N_2).	Phosphoric anhydride (P_2O_5).	Lime (CaO).	Magnesia (MgO).	Potash (K_2O).	Soda (Na_2O)	Humus.	Soil acidity (per cent $CaCO_3$).	Fine earth.	Source.	Remarks.
	Cm.	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*	*P. ct.*		
11	0- 30	2.08	3.38	0.095	0.038	0.42	-------	0.095	-------	-------	-------	100	Tabacalera Estate, San Miguel, Tarlac.	This represents a considerable area of the alluvial soils of the section, much of which is devoted to the cultivation of sugar and rice. Sandy substratum.
12	30-150	2.71	3.53	0.054	0.038	0.39	-------	0.043	-------	-------	-------	100	do	Subsoil to No. 7. Almost pure yellow sand and over 1.5 meters in depth.
13	0- 15	3.01	4.54	0.095	0.049	0.77	0.22	0.059	0.21	0.75	-------	100	Near Moriones, Tarlac.	From east flank of Zambales Mountains, representing the level areas. Underlain with coarse and fine sands.
14	15- 50	4.31	5.12	0.062	0.050	0.78	0.26	0.077	0.16	0.52	-------	100	do	Subsoil to No. 14.
15	0- 15	4.56	5.84	0.074	0.039	0.40	0.29	0.053	0.16	0.39	0.00750	97.6	Angat, Bulacan	From southwest of presidencia, representing an area of 1,800 hectares of land included in the Norzagaray-Malolos irrigation project. Rice paddies.
16	15- 30	4.75	6.72	0.053	0.027	0.52	0.22	0.066	0.15	0.53	0.00313	95.3	do	Subsoil to No. 15.
17	100-125	5.84	7.34	0.071	0.060	0.83	0.57	0.090	0.27	0.44	0.00375	89.7	do	Taken from the side of a carabao road near No. 15.

TABLE XIII.—*Mechanical analyses of miscellaneous Luzon soils.*

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1–0.5 mm.	Medium. sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.		
	Cm.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
1	0– 25	0	0	0.8	2.3	7.7	19.6	27.1	30.7	11.8	San Fernando, Pampanga.	Sugar-cane field. Below a depth of 25 centimeters this is underlain by a yellow clay subsoil. At about 1 meter from the surface a fine yellow sand substratum is encountered.
2	25– 50	0	0	0.3	1.0	7.8	20.0	24.1	29.8	17.0	do	Subsoil to No. 1.
3	0– 25	0	0	3.7	14.6	27.6	10.8	9.5	17.9	15.9	Camp Stotsenberg, Pampanga.	From near-by foothills. Underlain by yellowish clay at about 25 centimeters. It is a loam of residual origin adjacent to which are alluvial deposits consisting principally of coarse sand.
4	25– 50	0	0	2.6	13.5	26.6	11.0	6.9	18.7	20.7	do	Subsoil to No. 3.
5	0– 30	2.3	5.0	10.0	25.2	40.0	10.7	3.7	6.6	3.8	Near Magalang, Pampanga.	Sugar land representing a type of soil generally found in the valley of that section of Pampanga. Sandy for a depth of at least several meters.
6	30–150	0	9.4	10.9	26.3	47.0	7.4	2.2	3.7	2.5	do	Subsoil to No. 5.
7	0– 30	0	0	0.8	4.5	22.1	20.7	22.3	21.0	8.6	Florida Blanca, Pampanga.	Hacienda Bernia, cultivated in sugar cane.
8	0– 30	0	0	0.3	1.8	3.6	25.5	27.7	32.8	8.3	Dinalupihan, Bataan.	1 kilometer from Casa-Hacienda on Gutat road. Cultivated in sugar cane.
9	0– 30	0	0	0.5	4.2	6.7	16.8	24.9	35.6	11.3	do	0.5 kilometer from Casa-Hacienda. Sugar land.

TABLE XIII.—*Mechanical analyses of miscellaneous Luzon soils*—Continued.

No.	Specimen.	Detritus not passing—		Fine earth, water-free basis.							Source.	Remarks.
		2 mm. sieve.	1 mm. sieve.	Coarse sand 1–0.5 mm.	Medium sand 0.5–0.25 mm.	Fine sand 0.25–0.10 mm.	Very fine sand 0.10–0.05 mm.	Silt 0.05–0.01 mm.	Very fine silt 0.010–0.002 mm.	Clay less than 0.002 mm.		
	Cm.	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*	*Per ct.*		
10	0– 30	0	0	0.7	8.5	31.2	16.7	18.1	16.6	8.2	Between Gutat and Dinalupihan, Bataan.	From Hacienda-Velez. Cultivated in sugar cane.
11	0– 30	0	0	4.4	19.5	32.2	10.1	8.5	15.2	10.1	Tabacalera Estate, San Miguel, Tarlac.	This represents a considerable area of the alluvial soils of the section, much of which is devoted to the culture of sugar and rice. Sandy substratum.
12	30–150	0	0	3.9	18.0	33.7	10.1	8.2	12.6	13.5	do	Subsoil to No. 7. Almost pure yellow sand and over 1.5 meters in depth.
13	0– 15	0	0	2.5	9.1	34.4	17.3	12.4	13.0	11.3	Near Moriones, Tarlac.	From east flank of Zambales Mountains, representing the level areas. Underlain with coarse and fine sands.
14	15– 50	0	0	3.5	8.5	22.1	15.5	12.7	18.6	19.1	do	Subsoil to No. 14.
15	0– 15	0	2.4	4.3	6.0	15.8	14.6	18.1	23.4	17.8	Angat, Bulacan.	From southwest of presidencia, representing an area of 1,800 hectares of land included in the Norzagaray-Malolos irrigation project. Rice paddies.
16	15– 30	0	4.7	4.3	5.8	12.4	12.1	16.5	22.7	26.2	do	Subsoil to No. 15.
17	100–125	3.5	6.8	11.6	7.1	18.5	9.6	10.1	20.6	22.5	do	Taken from the side of a carabao road near No. 15.

ILLUSTRATIONS

PLATE VI

FIG. 1. The first group of terraces north of Cusarang. *Cf.* No. 11, Tables VI and VII. (Photograph by Beyer.)

2. Camote field. Arrival of the party of the Secretary of the Interior, Bagnin, Lepanto, 1909. (Photograph by Martin.)

PLATE VII

FIG. 1. Coconuts in fruit, San Ramon farm, Mindanao. Note the large number of nuts. (Photograph by Martin.)

2. Hemp (*Musa textilis* Née). La Carlota, Occidental Negros. (Photograph by Bureau of Agriculture.)

TEXT FIGURES

FIG. 1. Types of soils of the Batangas area.

2. Soil map, Ambalangan-Dalin, Pangasinan.

3. Legaui Plateau, Ifugao, Mountain Province.

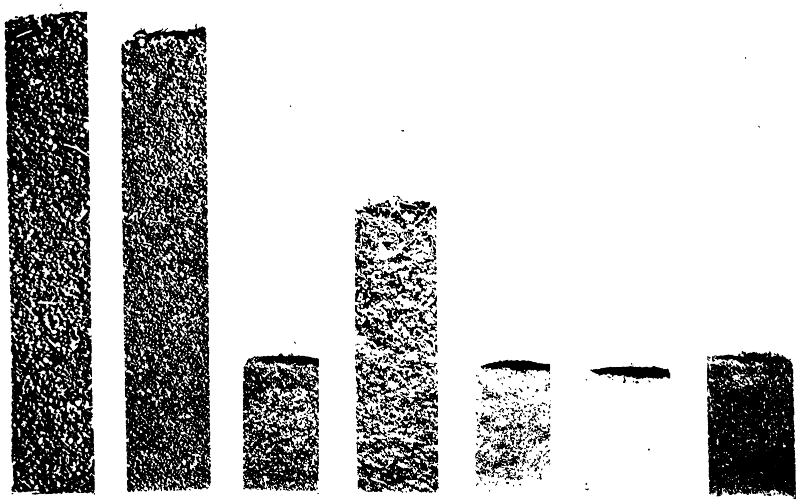

Fig. 1. Fractions of a sandy soil.

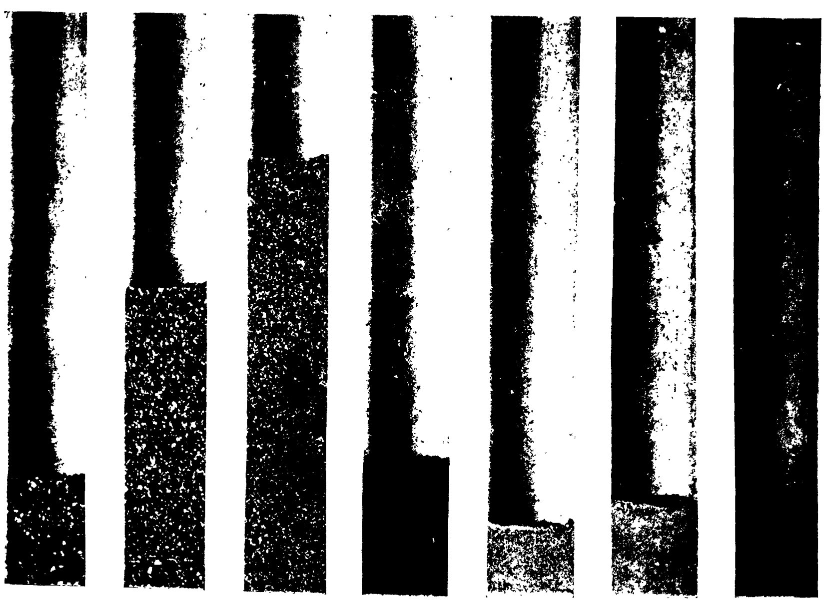

Fig. 2. Fractions of a fine sandy loam.

PLATE I.

Fig. 1. Fractions of a loam coconut soil.

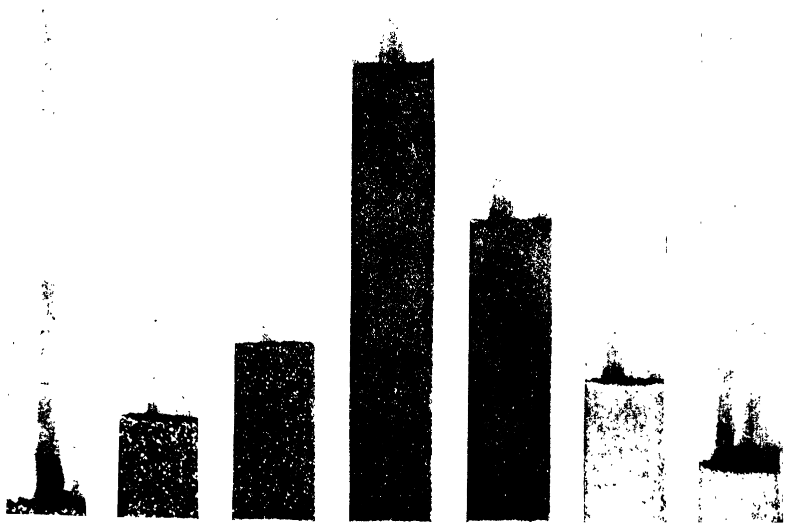

Fig. 2. Fractions of a soil approximating an ideal loam.

PLATE II.

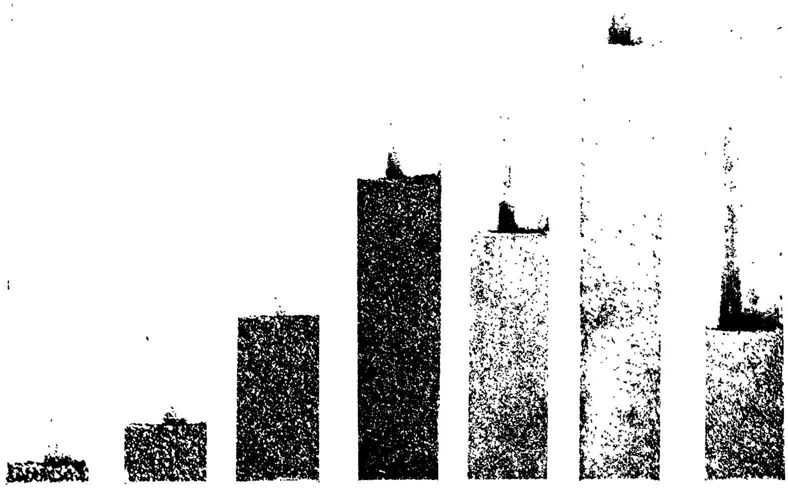

Fig. 1. Fractions of a clay loam.

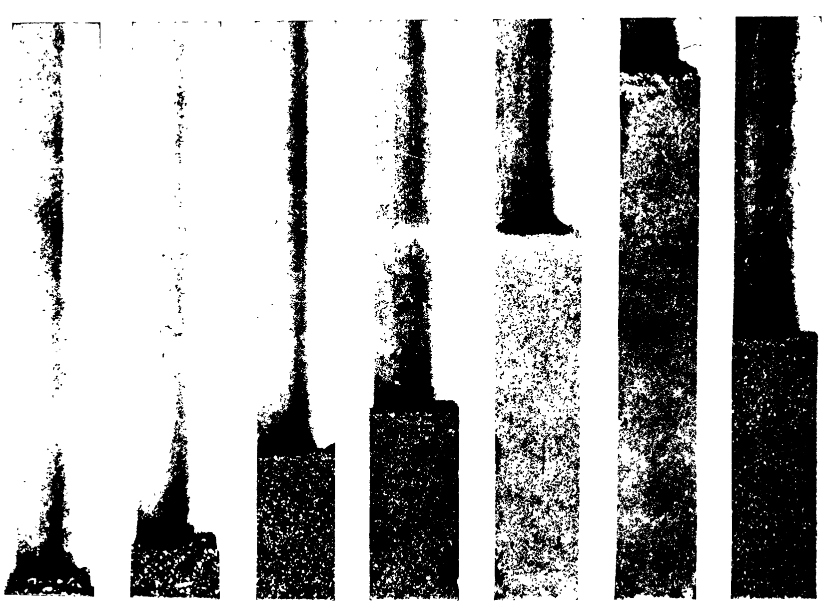

Fig. 2. Fractions of a clay coconut soil.

PLATE III.

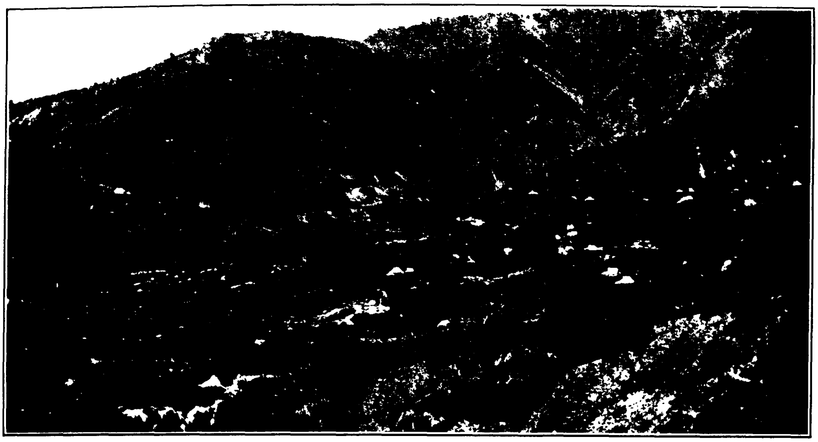

Fig. 1. View from Updas toward Lutab.

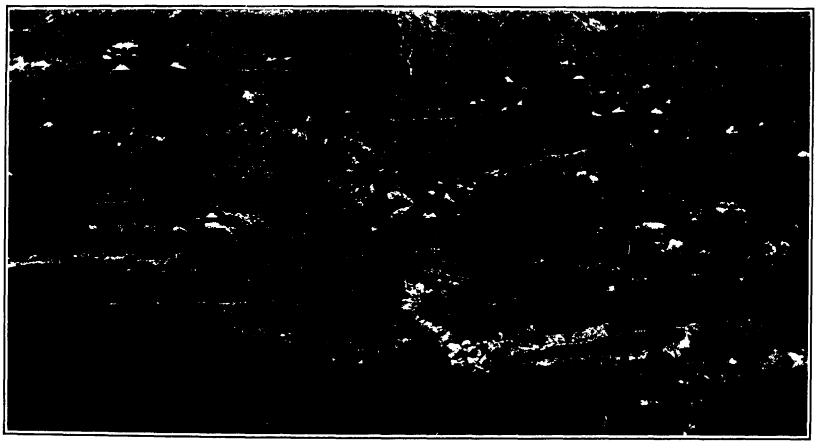

Fig. 2. View from Lutab toward Bakung and Updas.

Fig. 3. Coffee trees and rice terraces near Cabayan.

PLATE IV. THE AGNO RIVER VALLEY.

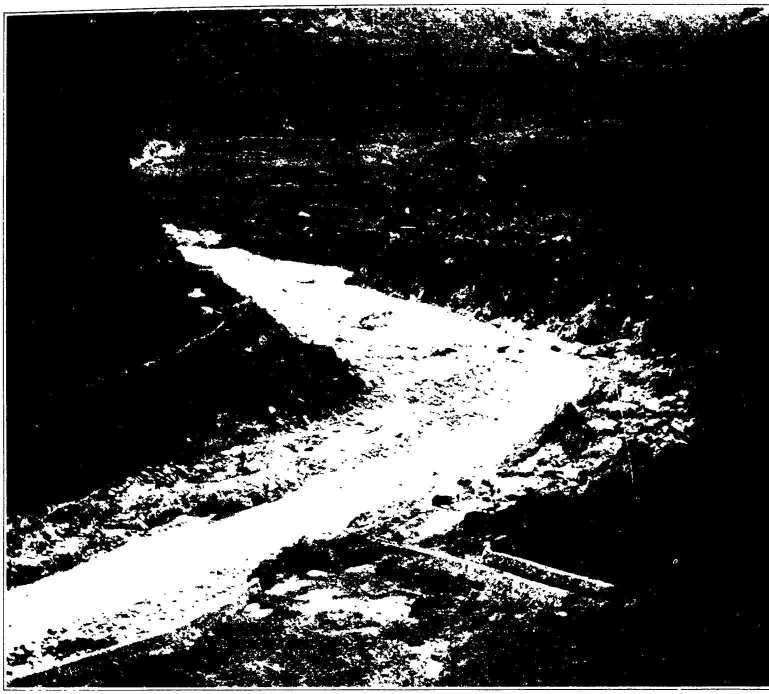

Fig. 1. Looking up the Agno River.

Fig. 2. Terraces at Cusarang.

PLATE V.

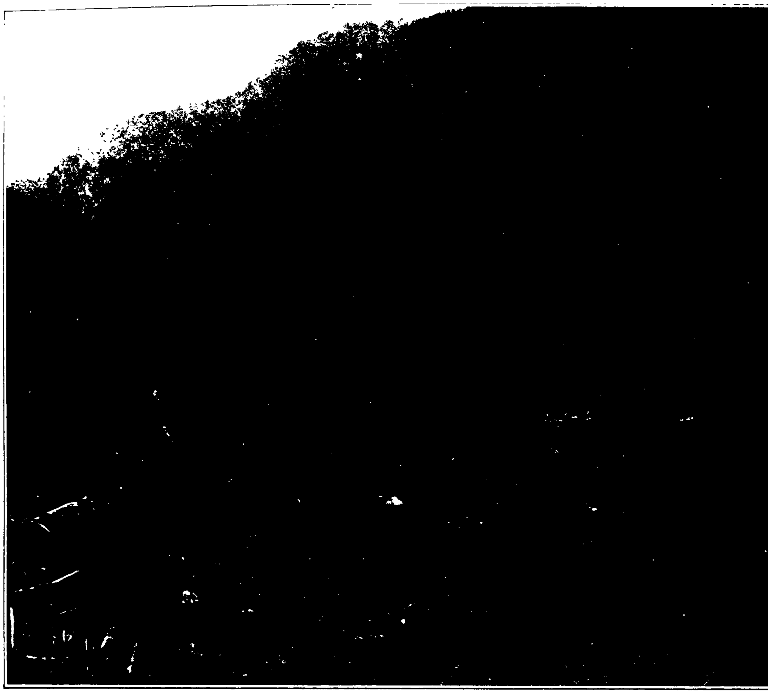

Fig. 1. Terraces at Cusarang.

Fig. 2. Camote field at Bagnin.

PLATE VI.

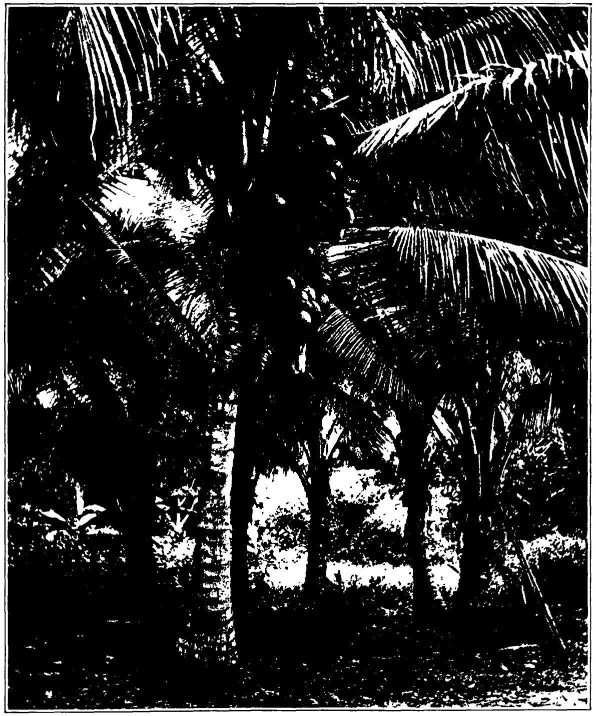

Fig. 1. Coconuts in fruit, San Ramon, Mindanao.

Fig. 2. Hemp, La Carlota, Occidental Negros.

PLATE VII.

A QUANTITATIVE DETERMINATION OF THE RADIUM EMANATION IN THE ATMOSPHERE AND ITS VARIATION WITH ALTITUDE AND METEOROLOGICAL CONDITIONS

By J. R. WRIGHT and O. F. SMITH

(From the Department of Physics, University of the Philippines)

One text figure

PART I. A QUANTITATIVE DETERMINATION OF THE RADIUM EMANATION IN THE ATMOSPHERE AT MANILA *

During the last few years the attention of physicists has been directed more and more to a study of atmospheric electricity. A complete study of the problem involves a thorough investigation of several more or less closely related factors, one of the most important being the determination of the amount of radioactive substances in the atmosphere of the earth.

The presence of radioactive substances in the atmosphere was first conclusively shown by the work of Elster and Geitel [1] in 1900. Making use of the discovery that an active deposit was collected on a negatively charged wire exposed in the presence of the emanation from thorium or radium, they stretched a negatively charged wire in the open air for several hours. Tests made by the electrical method gave convincing evidence that an active deposit had been collected on the wire from an emanation in the atmosphere. The active deposit thus collected was later shown by Bumstead,[2] Blanc,[3] Dadourian,[4] and others to be a mixture of the active deposits of both radium and thorium, the relative proportions depending on the length of the exposure of the wire. The first attempt to determine the actual amount of radium emanation in the atmosphere was made by Eve [5] by comparing the active deposit collected on a negatively charged wire from a definite volume of air with that collected from air containing a known quantity of radium emanation. However, the uncertainty of this method due to changes in meteorological conditions is so great that it does not afford an accurate means of determining the actual amount of radium emanation in the atmosphere. Eve [6] and Satterly,[7] making use of the discovery by Rutherford [8] that charcoal made from the shells of coconuts possesses the property of absorbing radium emanation, obtained

* Much of the equipment for this work was furnished by the Bureau of Science, and the work was done in a laboratory of that Bureau.

[1] *Phys. Zeitschr.* (1901), **11**, 560.
[2] *Am. Journ. Sci.* (1904), IV, **18**, 1.
[3] *Phil. Mag.* (1907), **13**, 378.
[4] *Le Radium* (1908).
[5] *Phil. Mag.* (1905), **10**, 98.
[6] *Ibid.* (1907), **14**, 724; (1908), **16**, 622.
[7] *Ibid.* (1908), **16**, 584.
[8] *Nature* (1906), **74**, 634.

direct determinations of the radium-emanation content. In order to attain this end, air was passed at a known rate for a given time through tubes containing the coconut charcoal, which absorbed the emanation from the air. At the same time air was bubbled through a solution of radium bromide containing a known amount of radium, and the emanation from the solution and the air was collected in another charcoal tube. The emanation absorbed in the charcoal was then driven off by heating to a dull red heat, collected over water in aspirators, and finally measured by passing into an ionization chamber connected either with an electroscope or an electrometer. The emanation in a given volume of air can then be calculated from the ratio

$$\frac{\text{emanation generated in the standard solution in a known time}}{\text{emanation in a known volume of air}},$$

provided the charcoal tubes absorb the same fraction of the total amount of emanation passing through them. Since the method is a comparative one, the determination should be independent of variation of meteorological conditions. Ashman [9] and Satterly [10] determined the amount of emanation in the atmosphere by another method. Air was passed through coils immersed in liquid air, and the amount of emanation condensed in the tube then measured. Rutherford and Soddy had previously shown that radium emanation is condensed at a temperature of about $-150°$.

It is hard to decide from the data at our command which is the better method. Satterly, in his paper published in 1908, makes the statement that "both methods gave about the same results for the emanation in the air, but the method of the condenser is quicker and more accurate than the charcoal method," but in a later article on the subject makes a diametrically opposite statement without giving any reason for his change of opinion.

The following average results have been obtained for the radium-emanation content of the atmosphere by Eve in Montreal, Satterly in Cambridge, and Ashman in Chicago:

Eve, 60×10^{-12} gram Ra per cubic meter.
Satterly, 100×10^{-12} gram Ra per cubic meter.
Ashman, 96×10^{-12} gram Ra per cubic meter.

When the present series of observations was started, liquid air was unobtainable in Manila. Consequently, we were limited in our choice to the charcoal-absorption method. During the

[9] *Am. Journ. Sci.* (1908), 119.
[10] *Loc. cit.*

past year a liquid-air plant has been received, and we expect in the near future to be able to check our results obtained with the charcoal method by observations with the liquid-air condenser. Since the general method of procedure which we finally adopted is not radically different from that of Eve and Satterly, our results ought to be directly comparable. A portion of a standard solution of radium bromide prepared by Rutherford, Boltwood, and Eve was kindly furnished us by Professor Eve. This solution contains 6.28×10^{-9} gram of radium per cubic centimeter, being of the same strength as that used by both Eve and Satterly. At first we used 0.5 cubic centimeter of the standard, diluting it with distilled water to 50 cubic centimeters, but we found that the emanation given off from the solution in the time of a test was considerably greater than that collected from the volume of air with which we were dealing. For a comparative method it is desirable to deal with approximately equal amounts of emanation in the two branches of the experiment. Consequently, in our later tests we used 0.1 cubic

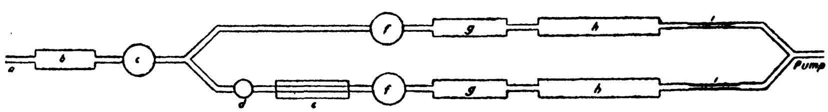

FIG. 1. Collecting apparatus. *a*, Inlet; *b*, cotton-wool tube; *c*, distributing bottle; *d*, standard solution; *e*, condensers; *f*, sulphuric acid bottles; *g*, calcium chloride tubes; *h*, charcoal tubes; *i*, manometers.

centimeter of the standard solution, diluting it as before to 50 cubic centimeters. This gave us for our standard a solution containing 6.28×10^{-10} gram of radium.

The arrangement of apparatus for the determination of the amount of radium emanation in the atmosphere is shown in fig. 1. The air to be tested was drawn through a tube projecting from a second-story window of the Bureau of Science at an elevation of about 10 meters. In order to extract all the dust from the air, a tube containing cotton wool was placed between the intake and the distributing bottle. From the distributing bottle the current of air was divided into two exactly equal parts, one-half passing through the branch containing the radium-bromide solution, the other half passing along what we have been pleased to call the "air-emanation" branch.

The bottle containing the radium-bromide solution was so arranged that it could be heated by immersing in a solution of sodium chloride. Both a spherical and a cylindrical condenser were attached in series to the bottle to prevent loss of the solution during the process of heating.

Although it has been fairly well established that the humidity of the air does not affect the efficiency of the charcoal as an absorber of the emanation, still we deemed it advisable to dry the air thoroughly before it reached the charcoal. The air during the greater part of the year in Manila has an extremely high absolute humidity, and the presence of a great amount of moisture in the charcoal is very annoying when it comes to heating the tubes. Since neither sulphuric acid nor calcium chloride seem to absorb the emanation, we first passed the air through a bottle containing sulphuric acid and then through tubes filled with calcium chloride. Most of the water was extracted from the air by the acid which was renewed about once a month.

The charcoal tubes.—The first tubes tried were of fused quartz, 1 meter long, having diameters of about 1.2 and 1.6 centimeters, respectively. The inequality in the diameters made it very difficult to regulate the amount of charcoal in the tubes so that the absorption in the two branches was exactly equal. Consequently, after a few preliminary experiments, these tubes were replaced by electrosilica tubes, 60 centimeters long and having a uniform bore of 1.5 centimeters. These tubes were filled to within about 6 centimeters of the ends with granulated coconut charcoal, each tube holding 70 grams. Two of these tubes were placed in series in each branch of the experiment, so that the air had to pass through 140 grams of charcoal. After collecting the emanation, the tubes which had been connected in series were heated in parallel in a tubular electric furnace to a bright red heat. Tests were made on the relative absorption of the two sets of tubes, no difference being detected.

The manometers.—The rate of flow of the air through the tubes was measured by means of water manometers across glass capillary tubes. The manometers were carefully graduated for different rates of flow, and the corresponding curve plotted. The combined error of graduation and reading was not over 2 per cent.

The suction pump.—At first a filter pump attached to the city water system was tried, but the water pressure was subject to frequent and rather large variations, and we were compelled to substitute for the filter pump a motor-driven oil pump. By placing in the system a large equilibrating bottle and a mercury regulator, we were able to obtain an almost absolutely steady flow of air for any desired length of time. The rate of flow was regulated by means of pinch cocks placed on the rubber tubing between the pump and manometers.

The electroscope.—The testing apparatus used was a Spindler and Hoyer aluminum-leaf electroscope with an ionization chamber attached. The aluminum leaf in these electroscopes has a fine quartz fiber attached to one edge which makes it possible to obtain very accurate readings with the aid of the reading microscope. The ionization chamber was 38 centimeters high and 7.8 centimeters in diameter, giving a volume of 1,820 cubic centimeters, and was provided with both an inlet and an outlet tube so that the chamber could easily be exhausted and refilled with the air containing the emanation. The electroscope with the attached ionization chamber had an electrical capacity of 8.7 e. s. units, the range of the scale of 100 divisions being approximately from 368 to 302 volts. Therefore, the voltage on the leaf was sufficient to produce saturation currents in a chamber of the size used. The natural leak was almost absolutely constant at 0.022 division per minute.

The ionization chamber was permanently attached through one opening to a mercury manometer and through the other opening to a Geryk oil pump and to 2 aspirator bottles, all connected in parallel, so that any one could be put in direct connection with the chamber. Between the pump, aspirators, and chamber were placed two tubes, one containing calcium chloride and the other phosphorus pentoxide, permitting all the air passing into the chamber to be thoroughly dried.

Method of taking readings.—For comparative measurements it is essential that a definite course of procedure be adopted and adhered to throughout the entire investigation. After a few preliminary experiments, we adopted the following method of taking measurements on the emanation collected. The air-emanation tubes were connected in parallel to one aspirator and heated to a bright red heat, the temperature for the different determinations being practically the same, equal currents being always passed through the electrical furnace for the same length of time. The tubes were then rapidly but thoroughly flushed until the aspirator was filled down to a definite mark. The air containing the emanation was then passed into the ionization chamber through the calcium chloride and phosphorus pentoxide tubes, care being taken finally to flush the tubes with air so that all the emanation would be carried into the ionization chamber. The chamber had been made with the necessary volume to accomodate all the gas driven off from 140 grams of charcoal with a liberal margin for flushing. The electroscope readings were always taken over practically the same region of the scale, the reading being started as nearly as possible

thirty minutes after introducing the emanation into the chamber. The deflection of the aluminum leaf for the following thirty minutes was then recorded. By this method we always obtained the reading over approximately the same part of the decay curve for radium emanation, thereby making the electroscope readings directly comparable. The air-solution tubes were then heated and the radioactivity of the gas measured in exactly the same way, correction in every case being made for the decay of the emanation in the period of time intervening between the collecting and testing of the gas.

PRELIMINARY EXPERIMENTS

The accuracy of the determination of the radium-emanation content of the atmosphere by the charcoal method depends to a large extent on the efficiency of the charcoal as an absorber of the emanation under the conditions of the experiment. Satterly,[11] in the course of his work on the amount of emanation in the atmosphere, made a careful investigation of the following:

(*a*) Is the amount of emanation absorbed from the air always the same fraction of the total amount in the air whatever that amount may be, other experimental conditions remaining the same?

(*b*) In the case when the air flowing to the charcoal contains a constant percentage of emanation, is the amount absorbed by the charcoal proportional to the time the air current is flowing, or does the charcoal show signs of saturation?

(*c*) Does the amount of emanation absorbed from the air depend on the humidity of the air?

(*d*) What is the percentage of emanation absorbed in any particular case?

From his results he drew the following conclusions:

(*a*) That with weak solutions the amount of emanation absorbed in short exposures of the same time for the same strength of air stream is proportional to the strength of the solution.

(*b*) That with the same solution and strength of air stream the amount absorbed for exposures of different times does not increase in proportion to the time of exposure but falls off, showing that the charcoal is getting saturated.

(*c*) That under the condition of the experiments the amount of emanation absorbed does not depend on the humidity of the air.

(*d*) That with tubes 8 sq. cm. in cross section containing a column 30 cms. long of coarsely powdered coconut charcoal the amount of emanation absorbed when the air stream is 0.5 liter per minute and the exposure in 21 hours is only 62 per cent of the total amount of emanation carried to the tube.

[11] *Phil. Mag.* (1910), **20**, 778.

Although Satterly's results seemed fairly conclusive, we thought it desirable, since we were working under different climatic conditions, to repeat some of the experiments before starting a long series of observations on the variation of the emanation content with meteorological conditions. Several other points also demanded consideration. These preliminary experiments occupied a period of about eight months.

In the preliminary experiments the points of especial investigation were the following:

(1) Is the standard solution put into the so-called "steady state" by bubbling air through the cold solution for a period of from two to three hours or is it necessary to boil the solution? If the bubbling of air through the cold solution does not take out the emanation as fast as it is formed, what per cent is taken out by the process?

(2) Does the charcoal become saturated with emanation for the small amounts dealt with in the experiment?

(3) Does the charcoal itself contain radium; that is, is there an accumulation of emanation in the charcoal itself with time?

TESTS ON THE FIRST POINT

Since a solution of radium bromide which had been allowed to stand for some time would have accumulated radium emanation, it is necessary before starting a test to put the solution into what has generally been called the "steady state;" that is, extract from the solution all accumulated emanation. Boltwood has shown experimentally that the radium emanation is completely removed from a solution of radium bromide by rapid boiling for several minutes. But since a test on the emanation in the air occupies a period of several hours, it is inconvenient to boil the solution for that length of time, even if by the use of condensers the possibility of bodily carrying over some of the radium bromide could be entirely eliminated. Both Satterly and Eve were content with bubbling air through the cold solution, assuming that not only was the solution first put into the steady state, but that during a test the emanation would be removed as rapidly as it was formed. However, no account is given of any effort to prove the correctness of their assumption.

For an accurate determination of the emanation content of the atmosphere, it is not sufficient to show that bubbling air through the cold solution does not extract all the emanation, but it is also necessary to determine accurately what fraction of the whole amount is removed from the solution under the conditions

of the experiment. In order to accomplish this end, it was necessary to take a large number of observations. The results are summarized in Table I.

TABLE I.—*Radium emanation obtained from a given solution of radium bromide by bubbling air through the solution under different conditions.*

Date.	Duration of exposure.	Radium in standard solution. Grams $\times 10^{9}$.	Electroscope reading in divisions per minute. Due to examination collected in time of exposure.	Electroscope reading in divisions per minute. Deduced on basis of 20-hour exposure for solution containing 0.628×10^{-9} gram of Ra.	State of solution during exposure.	Method used to put solution in "steady state."
Series I.	*Hrs.*					
Oct. 25, 1912	3	3.14	0.528	0.720	Room temperature.	Air bubbled through cold solution for 3 hours.
Nov. 8, 1912	3	3.14	0.580	0.791		
Mean				0.755		
Series II.						
Nov. 25, 1912	5	0.628	0.240	0.960	Room temperature.	Air bubbled through boiling solution for 1 hour and then through cold solution for 2 hours.
Dec. 4, 1912	5	0.628	0.314	1.256		
Dec. 6, 1912	5	0.628	0.332	1.328		
Dec. 11, 1912	5	0.628	0.311	1.244		
Dec. 19, 1912	5	0.628	0.320	1.280		
Dec. 26, 1912	5	0.628	0.346	1.384		
Jan. 10, 1913	5	0.628	0.306	1.224		
Mar. 3, 1913	5	0.628	0.333	1.332		
Mean				1.251		
Series III.						
Oct. 30, 1912	3	3.14	0.751	1.023	Boiling	Air bubbled through boiling solution for 1 hour.
Oct. 31, 1912	3	3.14	0.880	1.201		
Nov. 4, 1912	3	3.14	0.688	0.938		
Nov. 6, 1912	3	3.14	0.797	1.089		
Mean				1.063		
Series IV.						
Oct. 28, 1912	3	3.14	1.063	1.448	Boiling	Air bubbled through cold solution for 4 hours.
Nov. 11, 1912	3	3.14	1.070	1.459		
Mean				1.453		
Series V.						
Nov. 26, 1912	5	0.628	0.388	1.552	Boiling	Air bubbled through boiling solution from 1 to 1.5 hours.
Dec. 5, 1912	5	0.628	0.378	1.512		
Dec. 10, 1912	5	0.628	0.396	1.584		
Dec. 20, 1912	5	0.628	0.412	1.648		
Dec. 29, 1912	5	0.628	0.383	1.532		
Jan. 1, 1913	5	0.628	0.410	1.640		
Mean				1.578		

Table I shows that in every case the emanation obtained from bubbling air through the cold solution is considerably less than that obtained from the boiling solution. The table is divided into 5 series according to the conditions existing during the tests. Series I, III, and IV were made on a solution containing 3.14×10^{-9} gram of radium, series II and V on a solution containing 6.28×10^{-10} gram. The conditions of the tests in series II and V were identical with those existing throughout the greater part of the work on the radium-emanation content of the air; therefore, the ratio of the mean of series II to that of series V will be used as a reduction factor in our final calculations of the radium emanation in the atmosphere. This ratio is equal to 0.792.

TESTS ON THE SECOND POINT

Since Satterly found that charcoal showed signs of saturation especially for tests extending over several hours, it was deemed advisable to determine whether under the conditions of our experiments evidence of saturation existed. Tests were first made by putting several of the electrosilica tubes which we were using in series. The results are shown in Table II.

TABLE II.—*Efficiency of coconut charcoal as an absorber of radium emanation.*

Date.	Strength of solution. Grams $\times 10^9$.	Number of tubes in series.	Duration of test.	Electroscope reading less natural leak.			
				Tube No. 1.	Tube No. 2.	Tube No. 3.	Tube No. 4.
			Hrs.				
Oct. 14, 1912	3.14	4	4	0.831	0.003	0.002	0.003
Oct. 17, 1912	3.14	3	4	0.935	0.048	0.002	....

The emanation in this case is apparently all absorbed in the first two tubes, the electroscope reading for the third and fourth being so small as to be easily within the limits of observational error, the natural leak having a mean value of 0.022. In Table III are given the results of a series of observations in which 2 tubes were placed in series and the duration of the tests varied from five to twenty hours. Although not so conclusive as the results of Table II, all evidence of saturation is lacking.

TABLE III.—*Relative absorption of radium emanation by coconut charcoal for exposures of different lengths.*

Date.	Duration of exposure.	Radium in standard solution in grams $\times 10^9$.	Electroscope reading in divisions per minute. Due to emanation collected from solution in time of exposure.	Electroscope reading in divisions per minute. Deduced on basis of emanation from solution in 20 hours.	Method used for putting standard solution in "steady state."	Remarks.
	Hrs.					
Dec. 19, 1912	5	0.628	0.320	1.280	Air was bubbled through boiling solution for 1 hour and then through solution at room temperature for 2 hours.	For collecting, 2 electrosilica tubes each containing 70 grams charcoal were placed in series. The tubes were heated in parallel to drive off the emanation.
Dec. 26, 1912	5	0.628	0.346	1.384		
Jan. 10, 1913	5	0.628	0.306	1.224		
Mar. 3, 1913	5	0.628	0.333	1.332		
Mean				1.305		
Mar. 4, 1913	10	0.628	0.698	1.396		
Feb. 26, 1913	15	0.628	1.098	1.464		
Feb. 24, 1913	20	0.628	1.273	1.273		

In the course of some experiments carried out on Mount Pauai, we had occasion to use some electrosilica tubes of much larger bore. The tubes which we had been using contained 70 grams of charcoal closely packed in a length of about 48 centimeters of the tube, 2 tubes always being used in series. In the larger tubes, 140 grams of charcoal occupied a length of about 40 centimeters, and, since the total weight of charcoal was the same, we assumed at first that the amounts of emanation absorbed would be at least approximately equal. But we soon found that for the same strength of solution and the same time of exposure the larger tubes were absorbing only about 50 per cent as much as the other tubes. The results are given in Table IV.

TABLE IV.—*Effect of the distribution of a given weight of charcoal on the amount of radium emanation absorbed.*

Date.	Duration of exposure.	Radium in standard solution in grams $\times 10^9$.	Electroscope reading in divisions per minute. Due to emanation from solution in time of exposure.	Electroscope reading in divisions per minute. Deduced on basis of emanation from solution in 20 hours.	Method used for putting standard solution in "steady state."	Remarks.
	Hrs.					
May 6, 1913	10	0.628	0.343	0.686	Air was bubbled through boiling solution for 30 minutes and then through solution at atmospheric temperature for 2.5 hours.	For collecting, 1 electrosilica tube containing 140 grams charcoal was used.
	20	0.628	0.449	[a] 0.449		
May 4, 1913	40	0.628	0.642	0.321		

[a] Mean of 7 determinations.

It is evident from a study of the results given in the last three tables that a phenomenon analogous to saturation does exist under certain conditions. The conditions under which the experiments, the results of which are given in Tables III and IV, were made were identical except for the distribution of the charcoal. In both experiments the same weight of charcoal was used, the charcoal being made at the same time and as nearly as possible of the same-sized granules, the only difference being that in the one case the emanation passed over 140 grams of charcoal closely packed in a length of 96 centimeters while in the other case it passed over the same amount of charcoal packed in a column about 40 centimeters long. The apparent conclusion is that the effect is not a case of saturation in the ordinary sense of the word, but rather due to a continual carrying forward of the emanation by the air current. The shorter the column of charcoal through which the emanation must pass, the greater the fraction of the total amount carried out. This probably explains why Satterly obtained evidence of saturation by lengthening the time of exposure, while at the same time varying the strength of the solution within fairly wide limits gave little evidence of the same effect. Assuming complete absorption for exposures of three hours or less, Satterly found that for a 21-hour exposure only about 62 per cent of the total amount is absorbed. As an explanation of this, it is sug-

gested that the absorption is twofold: a quick effect, a surface condensation, being followed by a slower effect, a diffusion into the interior. If this is the true explanation, then it is to be expected that for equal amounts of emanation passing over the charcoal in different periods of time the amount absorbed will be a direct rather than an inverse function of the time, since the longer the time the greater the effect of the slow diffusion into the interior. Taking Satterly's recorded results, we see that this is not the case. For instance, no saturation was found to be evident when the emanation from a solution containing 6×10^{-9} gram of radium was passed over charcoal for two hours and fifteen minutes, while an exposure of twenty-one hours to the emanation from a solution containing 6.28×10^{-10} gram showed saturation to the extent mentioned above, although in the first case a slightly greater amount of emanation passed over the charcoal. It seems that the simple explanation that we have advanced explains the whole phenomenon. For a long exposure, a part of the emanation absorbed in the earlier hours of the experiment is caught up by the air current and gradually carried onward and finally entirely out of the tube. This will noticeably be the case when the charcoal is packed in a short length of the tube, the best distribution of a given weight of charcoal, as is also shown by our experiments, being that obtained in a long tube of small bore.

TESTS ON THE THIRD POINT

Investigation of the third point was suggested by the statement made by Satterly [12] that "charcoal itself contains radium, and if left to itself gradually accumulates radium emanation." Several tests were made to determine whether the charcoal which we were using gave any evidence of containing a trace of radium. It seems to be contrary to one's expectation that an organic substance like charcoal would contain radium unless it was contaminated with radium salts during the process of making. The results of our tests on this point are given in Table V.

[12] *Phil. Mag.* (1910), 20, 4.

TABLE V.—*Tests for radium in the coconut charcoal.*

Date.	Period of rest.	Natural leak of electroscope.	Electroscope reading in divisions per minute due to gas from charcoal.	Deflection due to emanation generated by charcoal in period of rest.	Emanation accumulated per day expressed in divisions per minute.
	Days.				
Oct. 12, 1912	4.0	0.032	0.019	—0.013	—0.004
Jan. 2, 1913	5.75	0.023	0.031	0.008	0.002
Jan. 2, 1913	9.2	[a] 0.024	0.024	0.000	0.000
June 9, 1913	74.0	[a] 0.077	0.067	0.010	0.002
June 16, 1913	81.0	0.016	0.036	0.020	0.003
June 17, 1913	36.0	0.016	0.031	0.015	0.002
June 19, 1913	38.0	0.016	0.031	0.015	0.002
Mean					0.0004

[a] The electroscope had just been set up, and the insulation leak was still large.

Table V shows that if there is any radium in the charcoal the amount is too minute to be detected by a sensitive electroscope. Since the deflection of the aluminium leaf was extremely slow, the readings were confined to one or two divisions, which increases the probability of a comparatively large observational error. The natural leak recorded was generally taken immediately before the observation on the gas driven off from the charcoal and as far as possible over the same part of the scale.

RADIUM-EMANATION CONTENT OF THE ATMOSPHERE

The theory upon which the calculations of the radium-emanation content of the atmosphere are based has been given at length by several writers on the subject. It can, however, be very simply deduced in the following manner:

If λ represents the radioactive constant of radium and T the duration of exposure, then λ T will be the emanation produced by 1 gram of the radium in the time T.

Now, if we assume that the emanation is removed from the solution of radium bromide as rapidly as it is formed, the decay factor will not enter into the calculations since the rate of decay of the emanation collected from the solution of radium is the same as that for the emanation from the air.

Therefore, if M is the amount of radium in radioactive equilibrium with the emanation in 1 cubic meter of free air and M′ the number of grams of radium in the solution, then

$$\frac{MV}{M'\lambda T}=\frac{d}{d_1}$$

where V is the total volume of air tested, d is the electroscope reading due to the emanation from V cubic meters of air, and

d_1 the electroscope reading corresponding to the emanation from M′ gram of radium.

Solving the equation for M, we get

$$M = \frac{M' \lambda T}{V} \cdot \frac{d}{d_1}$$

Eve arrives at the same result by a method somewhat more mathematical. Satterly neglected the decay of the emanation from the air during the time of the exposure, which introduces a slight error in his calculations, the error being almost negligible for short runs, but considerable for exposures of twenty hours or longer.

The results of observations on the radium-emanation content of the atmosphere extending over a period of about eight months are given in Table VI.

TABLE VI.—*Radium-emanation content of the atmosphere of Manila.*

Date.	Radium in solution in grams × 10^9.	Rate of flow of air stream in liters per minute.	Duration of exposure.	Electroscope reading in divisions per minute due to emanation in given volume of air.	Electroscope reading due to emanation from given volume of air and from standard solution.	Electroscope reading due to emanation from solution alone.	Emanation per cubic meter of air expressed in its radium equivalent. Grams × 10^{12}.
1912.			*Hrs.*				
July 26	3.140	0.33	20.0	0.139	2.258	2.009	81.06
Aug. 3	3.140	0.33	21.0	0.110	1.650	1.540	84.10
Sept. 12	3.140	0.33	20.0	0.450	3.668	3.218	164.60
Sept. 18	3.140	0.33	20.0	0.226	3.334	3.108	85.62
Sept. 23	3.140	0.33	20.0	0.326	4.932	4.590	100.50
Dec. 16	0.628	0.50	20.0	0.531	1.285	0.754	110.60
Dec. 23	0.628	0.50	20.0	0.774	1.658	0.884	137.50
1913.							
Jan. 2	0.628	0.50	20.0	0.526	1.267	0.741	110.40
Jan. 8	0.628	0.50	20.0	0.706	1.437	0.731	151.60
Jan. 16	0.628	0.50	10.0	0.136	0.533	0.399	53.50
Jan. 20	0.628	0.50	15.0	0.864	1.521	0.657	164.00
Jan. 22	0.628	0.50	5.0	0.096	0.314	0.218	69.20
Jan. 24	0.628	0.50	5.0	0.096	0.319	0.223	67.60
Jan. 26	0.628	0.50	20.5	0.282	0.982	0.700	63.45
Jan. 30	0.628	0.50	20.0	0.285	0.593	0.308	145.00
Feb. 4	0.628	0.50	5.0	0.053	0.173	0.120	69.39
Feb. 10	0.628	0.50	20.0	0.676	1.062	0.546	194.40
Feb. 12	0.628	0.50	20.0	0.472	1.354	0.882	84.02
Feb. 17	0.628	0.50	20.0	0.581	1.541	0.960	95.02
Mar. 11	0.628	0.50	20.0	0.491	1.495	1.004	76.78
Mar. 18	0.628	0.50	15.0	0.352	1.039	0.687	80.40
Mean							104.23

The mean of all the results obtained during the period from July to February inclusive is 104.23×10^{-12} gram. This value

is approximately the same as that found by Satterly for Cambridge by the same method and by Ashman at Chicago by the condensation method, but is considerably greater than that found by Eve for Montreal. If we take into account the fact that only a fractional part of the emanation is removed from the solution by bubbling air through the cold solution, then we must multiply the above result by the reduction factor, equal, according to our tests made under identical conditions, to 79.2 per cent. This would give us 82.5×10^{-12} ($104.28 \times 10^{-12} \times 0.792$) gram as the average amount of radium which would be necessary to maintain in radioactive equilibrium the radium emanation in 1 cubic meter of the atmosphere for Manila.

In our determinations the variation in the radium-emanation content of the atmosphere is somewhat less than that obtained by other observers, the ratio of the maximum to the minimum being approximately 4 to 1, while Eve gets a ratio of 7 to 1, Satterly 10 to 1, and Ashman 5 to 1. Since in most respects the annual variation of climatic conditions is much less for Manila than at any of the other places where similar observations have been taken, it is probably to be expected that the variation in the amount of radium emanation in the atmosphere would be less. The one meteorological factor subject to the greatest variation in Manila is the rainfall, which during several months of the year is extremely heavy, while for part of the year the precipitation may be almost negligible. The mean of the observations taken during the rainy season in July, August, and September is 103.2×10^{-12} gram as compared with 104.5×10^{-12} gram for observations in the months of December, January, and February, when the precipitation is very light. It is evident from these values that no reliable conclusion can be drawn from the average value of observations extending over a definite season of the year as to the variation with meteorological conditions. A comparison of the observed values of the radium-emanation content with the corresponding meteorological data from the Manila Observatory shows, however, an interesting and a fairly definite correlation. The Manila Observatory is located at a distance of about 400 meters from the Bureau of Science, so that the two sets of data practically coincide as to location. In Table VII are given the meteorological data which seem to have the most direct bearing on the variation of the emanation content. The only determinations which are omitted from the table are those for day exposures which, for reasons explained later, we have included in a separate table.

TABLE VII.—*Relation between the radium-emanation content and meteorological conditions in Manila.*

Date.	Pressure (mean).	Humidity.	Wind. Prevailing direction.	Wind. Total movement.	Rain, 24 hours beginning midnight.	Weather remarks.	Duration of exposure. From—	Duration of exposure. To—	Radium-emanation content in grams × 10^{12}.
1912.	*mm.*			*Km.*	*mm.*				
July 25	757.87	83.2	SW quad.	253.5	1.0	Rained every day, July 16-25			
July 26	57.89	81.9	S quad.	111.0			2.45 p. m.		
July 27	56.56	86.2	Variable	104.0	25.9			10.45 a. m.	81.60
Aug. 2	56.86	92.1	S quad.	252.5	43.8	Heavy rains from July 24 to Aug. 2			
Aug. 3	57.69	89.0	SW quad.	192.0	18.4		3.00 p. m.		
Aug. 4	57.86	86.9	SW quad.	142.5	0.3			12 noon	84.10
Sept. 11	56.91	85.3	SW quad.	301.5		No rain since Sept. 9			
Sept. 12	56.96	82.9	SW quad.	277.0	0.8		3.45 p. m.		
Sept. 13	56.15	86.5	SW quad.	264.0				11.45 a. m.	164.6
Sept. 17	55.03	88.2	SW quad.	405.0	9.0	Rain on Sept. 16			
Sept. 18	55.75	85.7	SW quad.	341.5	5.6		4.55 p. m.		
Sept. 19	55.04	81.9	SW quad.	241.0				12.55 p. m.	85.62
Sept. 22	58.62	76.3	SW quad.	194.5		No rain since Sept. 18			
Sept. 23	59.66	81.3	SW quad.	180.0	26.2		12.40 p. m.		
Sept. 24	59.03	87.2	Variable	76.0	0.3			8.40 a. m.	100.50
Dec. 15	61.24	83.8	NE by E	79.5	0.3	Only 3 mm. rain during first 15 days of December			
Dec. 16	60.76	76.9	NE	108.0			1.30 p. m.		
Dec. 17	60.35	82.5	W quad.	79.5	0.4			9.30 a. m.	110.60
Dec. 22	60.76	81.5	Variable	59.0		No rain since Dec. 17			
Dec. 23	60.35	80.5	WNW	61.0			12 noon		
Dec. 24	61.53	81.4	NNE	143.5				8.00 a. m.	137.50
1913.									
Jan. 1	61.34	94.3	N	168.0	33.3	Light rain the last 3 days of December			
Jan. 2	59.76	89.2	NW	119.5	2.1		3.00 p. m.		
Jan. 3	60.02	85.7	NE, WSW	82.0				11.00 a. m.	110.40

Jan. 7	59.81	83.3	WSW	107.5		Very light rain on Jan. 5 and 6			
Jan. 8	60.18	87.5	NE quad.	44.0			1.00 p. m.		151.60
Jan. 9	59.49	84.1	WNW, SE	90.5				9.00 a. m.	
Jan. 19	61.42	79.3	NE, WNW	168.5		No rain since Jan. 17			
Jan. 20	61.60	80.8	W quad.	94.5			5.15 p. m.		164.00
Jan. 21	61.59	81.8	WNW	99.0				9.15 a. m.	
Jan. 24	62.76	82.5	Variable	55.0	12.7	First rain since Jan. 17			
Jan. 25	63.88	89.8	N quad.	69.5	10.4		12.30 p. m.		63.45
Jan. 26	63.99	79.4	NNE	145.0				9.30 a. m.	
Jan. 29	64.14	81.3	N quad.	49.0	0.9				
Jan. 30	64.36	77.6	E	85.5			1.00 p. m.		145.00
Jan. 31	64.38	74.8	ENE	166.5				9.00 a. m.	
Feb. 9	61.28	73.6	SE	138.0		No rain since Jan. 29			
Feb. 10	62.08	79.1	W, NE quad.	106.5			1.30 p. m.		194.40
Feb. 11	62.93	78.4	N quad.	152.0				9.30 a. m.	
Feb. 12	62.93	70.4	NW quad.	159.0			1.30 p. m.		84.00
Feb. 13	62.66	76.6	WNW, SE	162.0				9.30 a. m.	
Feb. 16	63.72	71.3	ESE	210.0		No rain since Jan. 29			
Feb. 17	62.34	73.7	E	202.0			1.30 p. m.		95.02
Feb. 18	61.24	73.9	E quad.	196.0				9.30 a. m.	
Mar. 10	58.54	73.6	SSE	211.0		No rain since Mar. 7			
Mar. 11	58.95	70.0	ESE	241.0			1.00 p. m.		76.78
Mar. 12	58.78	72.3	NE, W	193.0				9.00 a. m.	
Mar. 17	59.43	63.9	ESE	243.5					
Mar. 18	59.25	68.9	SE	243.0			5.30 p. m.		80.40
Mar. 19	59.16	65.3	E	276.5				8.30 a. m.	

Observations of the radium-emanation content taken during, or immediately after, a period of rainy weather show a comparatively low value, while those corresponding to the periods of fair weather are almost invariably high. This is especially noticeable during the months when rainy and fair periods alternate. It is regretted that until the present time no observations have been taken during an exceptionally heavy typhoon, when extremely low values might be expected.[13] In the months of the dry season, when the precipitation is very light, there seems to be a tendency for the emanation content to decrease. This may be due to a certain extent to the prevailing direction of the wind during that season or possibly to the comparatively high values of the total wind movement during the time of exposure. A high value of the daily wind movement is generally associated with a low value of the emanation content, although this effect is partly masked by the fact that heavy rains and a high wind velocity generally go hand in hand. No correlation is noticeable with a rising or falling barometer, which is contrary to the conclusion drawn by Simpson [14] from observations taken in Lapland in 1906 by the active-deposit method. Simpson also found that the radioactivity of the atmosphere increases as the humidity increases and vice versa, but if such a relation exists it is masked in our determinations by other factors. It is very likely, however, that the effect observed by Simpson by the active-deposit method is due to a change in nucleation of the atmosphere rather than to a variation in the radium-emanation content.

In the above discussion of the variation with meteorological changes we omitted the observations taken entirely during the daytime, for it was found that the strictly day exposures gave much lower values on the average than those extending throughout the night. In Table VIII the day and night observations are compared.

[13] Since writing the above discussion we have obtained determinations during typhoon weather which show much lower values than any previously obtained for Manila.

[14] *Phil. Trans.* (1905), A, 205, 61-87.

TABLE VIII.—*Comparison of day and night determinations of the radium-emanation content of the atmosphere of Manila.*

Date.	Duration of exposure.			Emanation per cubic meter of air expressed in the radium equivalent. Grams $\times 10^{12}$.	Date.	Duration of exposure.			Emanation per cubic meter of air expressed in the radium equivalent. Grams $\times 10^{12}$.
	From—	To—	Length of time.			From—	To—	Length of time.	
1912.	*p. m.*	*a. m.*	*hrs.*		1913.	*a. m.*	*p. m.*	*hrs.*	
July 26-27	2.45	10.45	20.0	81.06	Jan. 16	11.25	9.25	10.0	53.50
Aug. 3-4	3.00	[a] 12.00	21.0	84.10	Jan. 22	11.00	4.00	5.0	69.20
Sept. 12-13	3.45	11.45	20.0	164.60	Jan. 24	11.45	4.45	5.0	67.60
Sept. 18-19	4.55	[b] 12.55	20.0	85.62	Feb. 4	11.10	4.10	5.0	69.39
Sept. 23-24	12.40	8.40	20.0	110.50					
Dec. 16-17	1.30	9.30	20.0	110.60					
Dec. 23-24	[a] 12.00	8.00	20.0	137.50					
1913.									
Jan. 2-3	3.00	11.00	20.0	110.40					
Jan. 8-9	1.00	9.00	20.0	151.60					
Jan. 20-21	5.15	9.15	15.0	164.00					
Jan. 26-27	12.30	9.30	20.5	63.45					
Jan. 30-31	1.00	9.00	20.0	145.20					
Feb. 10-11	1.30	9.30	20.0	194.00					
Feb. 12-13	1.30	9.30	20.0	84.02					
Feb. 17-18	1.30	9.30	20.0	95.02					
Mar. 11-12	1.00	9.00	20.0	76.78					
Mar. 18-19	5.30	8.30	15.0	80.44					
Mean of night runs				114.05	Mean of day runs				64.92

[a] Noon. [b] p. m.

Although we have taken few entirely night exposures, the observations which are so classified extend throughout the entire night. Generally, the exposure was started in the late afternoon and extended until about the middle of the following forenoon. The day runs were all taken in the afternoon, extending in one case to 9.25 p. m. Although sufficient observations have not been taken to draw any general conclusions, the difference between the day and night exposures is too great to be explained as entirely accidental.

From the work of Simpson and Wright, Eve, and others on the radioactivity of the air over the sea, it would naturally be expected that for a place situated on the sea coast, where land and sea breezes are more or less regular, the emanation content of the atmosphere would be lower for the day than for the night.

A thorough study of the subject involves the careful mapping of the wind trajectories for the given location for the different seasons of the year and for the different parts of the day. By this means it should be possible to determine, at least approximately, whether the air tested had previously passed for any considerable time over the land or over the ocean.

Several observers have made determinations of the diurnal variation by the active-deposit method. Simpson [15] made three determinations a day—morning, noon, and evening—during the greater part of a year, and found a maximum in the morning and a minimum about midday. Gockel,[16] at Freiburg, likewise obtained a maximum in the early morning and sometimes a low value about noon. Dike,[17] at Cambridge, found a minimum at about 6 p. m. followed by a rapid increase to a maximum at 1 a. m., which was followed by a slight drop with another maximum at 4 a. m. Dike's observations, however, are not sufficiently extensive to justify any general conclusions. As has been pointed out, the active-deposit method is not adapted to an accurate determination of the emanation content, and the diurnal variation observed may be largely due to changes in the nucleation or other conditions of the atmosphere.

The solution of the problem of the diurnal and annual variation will be attained only by a series of careful observations extending over a long period of time. We plan to continue the observations during the coming year in the hope of being able to learn more concerning this interesting and important phase of the work.

PART II. VARIATION OF THE RADIUM-EMANATION CONTENT OF THE ATMOSPHERE WITH ALTITUDE

It has been shown by observations taken in different parts of the world that radium emanation is everywhere present in the atmosphere. The source of the emanation is undoubtedly the radium contained in the earth's crust. Since the half-value period of radium emanation is 3.86 days, it is to be expected that it will be transported by air currents to a considerable distance from its source before a large amount of its activity has been lost. Observations taken by Eve,[18] Simpson and Wright,[19] and others show that even over the centers of the

[15] *Loc. cit.*
[16] *Phys. Zeitschr.* (1904), 5, 591.
[17] *Terr. Mag.* (1906), 7, 125.
[18] *Phil. Mag.* (1907), 13, 248; *Terr. Mag.* (1909), 14, 25.
[19] *Proc. Roy. Soc.* (1911), A, 85, 175.

great oceans the air contains a considerable amount of radium emanation. Since tests of sea water have shown that its radium content is very low, the greater part of the emanation over the sea must be transported by air currents from the land. The question also arises, to what extent is the emanation carried upward before much of its activity is lost? The rate of diffusion of the emanation is too slow for it to reach any considerable height before losing most of its activity, but upward air currents may carry it to a comparatively high altitude. Nevertheless, it is to be expected that the amount of radium emanation in the atmosphere diminishes with altitude.

Flemming,[20] from balloon observations, found that a negatively charged wire collected about the same amount of radioactive deposit at an elevation of 3,000 meters as at the earth's surface. Saake [21] and Gockel,[22] from observations taken on mountain peaks, by the same method, found that the active deposit was greater at high altitudes than at sea level. W. Knoche,[23] likewise, obtained a high value for the active deposit at an elevation of 5,200 meters in the Bollivian Cordilleras.

The active-deposit method, however, is not adapted to an accurate determination of the radium-emanation content of the atmosphere, and it is very doubtful if the results at different altitudes have even a comparative value. Rutherford[24] appends his discussion of the results of Flemming, Saake, and of Gockel with the following remarks:

> It does not necessarily follow that the air at great altitudes contains more radium or thorium emanation, for the amount of active matter collected for a given volume distribution of emanation will depend on the pressure of the air and the amount of dust or *other nuclei*[25] in the atmosphere.

From the above discussion the importance of a direct determination of the radium-emanation content of the air at high altitudes is perfectly evident. The charcoal-absorption method is well adapted for obtaining observations at different altitudes which will be directly comparable. Since the method is a comparative one, each observation on the emanation in the air being taken simultaneously with a determination of the emanation

[20] *Phys. Zeitschr.* (1908), 9, 801.
[21] *Ibid.* (1903), 4, 626.
[22] *Ibid.* (1907), 8, 701.
[23] *Ibid.* (1912), 13, 440.
[24] Radioactive Substances and their Radiations. University Press, Cambridge (1913), 631.
[25] The italics are ours.

collected from a standard solution of radium bromide, changes of pressure and nucleation in the atmosphere will have no effect on the final results. The same is true for the ionization produced by the emanation introduced into the testing vessel. Consequently, the method should give an accurate determination of the amount of radium emanation contained in the atmosphere at any given altitude. In order to obtain results which would give the variation for altitude alone, it would be necessary to take observations from a balloon or other air craft, but the difficulties of carrying out observations of long duration under such conditions are practically unsurmountable. The only alternative was to take observations on a high mountain peak as nearly isolated as possible from surrounding peaks. In this case, the effect of altitude is obtained only in so far as the air currents are horizontal or descending rather than ascending. That this condition is approximately realized during a considerable portion of each day is evident from a study of the movement of clouds around a peak. Observations extending from late afternoon to early morning should give a fairly accurate test of the radium-emanation content of air which had not recently been in close contact with the surface of the earth.

After a careful survey of the available mountains of northern Luzon, Mount Pauai, elevation 2,460 meters, was chosen as the most suitable place on which to carry out a series of observations. Besides being the highest peak in the range, Mount Pauai afforded a source of water sufficiently near the top to provide the necessary water pressure for a good filter pump. The labor of transporting a complete laboratory equipment for the experiment over a distance of 90 kilometers from the nearest railway station and obtaining practically identical conditions as those existing in the well-equipped Bureau of Science laboratory of Manila was no easy task, but the results obtained more than repaid us for our trouble.

The apparatus for the work and its arrangement was practically a duplicate of that which we have already described as in use in Manila. However, one or two minor changes in the apparatus were necessary. In order to obtain a constant stream of air through the charcoal tubes, we were compelled to substitute a filter pump for the motor-driven oil pump. Under a constant pressure of 5 meters of water, the filter pump enabled us to obtain a flow of 1 liter of air per minute. The greatest variation in the rate of flow, as indicated by sensitive water manometers, was somewhat less than 1.5 per cent even for

exposures of forty hours. The tubular electric furnace, used in our former determinations, was replaced by an air-blast charcoal furnace which enabled us to heat the charcoal tubes to a bright red heat or, as near as the eye could tell, to the same temperature as formerly used. During all our work the charcoal tubes have always been heated until practically all the gas possible was driven off. The volume of gas given off by a definite weight of charcoal for any given distribution seems to be practically constant.

Since it was desirable that the results of observations on Mount Pauai should be directly comparable with those taken in Manila, the method of taking observations previously described was rigidly adhered to throughout the entire series of determinations, the results of which are given in Table IX. The rate of flow of air through each set of charcoal tubes was kept constant for all the exposures at 0.5 liter per minute. The same portion of the standard solution, containing 6.28×10^{-10} gram of radium, was used throughout the entire series.

TABLE IX.—*Radium-emanation content of the atmosphere of Mount Pauai.*

Date.	Duration of exposure.	Electroscope reading in divisions per minute due to emanation from—		Electroscope reading due to emanation from—		Emanation per cubic meter of air expressed in its radium equivalent. Grams $\times 10^{12}$.
		Given volume of air.	Given volume of air and standard solution.	Solution alone.	Solution for an exposure of 20 hours times decay factor.	
1913.	*Hours.*					
Apr. 23	20	0.042	0.455	0.413	0.480	15.97
Apr. 25	20	0.044	0.313	0.269	0.311	25.68
Apr. 28	20	0.087	0.462	0.375	0.455	36.42
May 1	20	0.070	0.444	0.374	0.434	29.39
May 3	20	0.087	0.407	0.320	0.372	42.68
May 4	40	0.045	0.522	0.477	0.321	14.81
May 6	10	0.035	0.354	0.319	0.686	17.22
May 7	10	0.051	0.354	0.319	0.686	24.96
May 8	20	0.028	0.475	0.447	0.518	9.83
May 10	20	0.073	0.563	0.493	[a] 0.572	24.34
Mean						24.13

[a] The last observation was taken with 2 tubes in series on the solution side, although only the first tube is taken into consideration in the calculation. The presence of the second tube may have had an influence on the absorption in the first tube, by changing the air current streams.

Expressed in terms of the radium equivalent, the mean value of the 10 determinations of the radium emanation per cubic

meter of the atmosphere of Mount Pauai is 24.13×10^{-12} gram. If we take into account the fact that bubbling air through the cool standard solution does not remove the emanation as rapidly as it is formed, then the above result should be multiplied by a factor somewhat less than unity. If we assume that this factor is approximately the same as that found under similar conditions in Manila, then it will have a numerical value of 0.792. Multiplying by this factor reduces the mean value to 19.11×10^{-12} gram per cubic meter. The assumption that the reduction factor will be the same for the two different localities may, however, be unjustifiable since both the air temperature and the atmospheric pressure are considerably different for the two places. The lower temperature would tend to decrease the reduction factor, while the decrease in pressure would probably have the opposite effect. It is to be regretted that the time at our disposal did not permit us to make any determinations of this factor at the higher altitude.

The ratio of the mean values of the radium-emanation content for Manila and Mount Pauai is approximately 4 to 1. The maximum value obtained on Mount Pauai is somewhat less than the minimum value obtained thus far for Manila. Since the amount of radium emanation in the atmosphere of any given locality undoubtedly varies between fairly wide limits with the variation in meteorological conditions, it is hardly to be expected that the same relation would exist for observations extending over a long period of time. But the values obtained at the elevation of 2,460 meters are so consistently lower than those found for Manila, which is practically at sea level, that there seems to be small chance to doubt that the radium-emanation content is lower for the higher altitudes.

Although the observations on Mount Pauai only extended over a period of about four weeks, nevertheless, they were taken under a great variety of meteorological conditions. The weather during the four weeks embraced the three following distinct types: (1) Bright, with exceptionally clear atmosphere; (2) cloudy, with light afternoon showers; and (3) typhoon, with a heavy downpour of rain. Each distinct type extended over a period of several days, so that observations taken during any given period should be fairly typical for such conditions. The variations of the radium-emanation content with the meteorological conditions are shown in Table X.

TABLE X.—*Relation between the radium-emanation content and meteorological conditions on Mount Pauai.*

Date.	Barometer.		Humidity.		Temperature.		Weather remarks.		Emanation per cubic meter of air expressed in its radium equivalent. Grams × 10^{12}.
	10 a. m.	4 p. m.	10 a. m.	4 p. m.	10 a. m.	4 p. m.	10 a. m.	4 p. m.	
1913.	*mm.*	*mm.*	P. ct.	P. ct.	°*C.*	°*C.*			
Apr. 22	576.6	576.0	78.5	99.9	17.8	15.3	Cloudy; showers	Cloudy; showers	
Apr. 23	76.0	75.5	89.3	89.3	18.5	17.5	Fair	Cloudy	15.97
Apr. 24	76.0	75.3	75.4	93.0	18.0	15.3	do	do	
Apr. 25	76.0	75.5	82.0	81.7	18.5	17.5	do	Showers	25.68
Apr. 26	77.1	76.0	74.7	78.4	19.2	16.0	do	Partly cloudy	
Apr. 27	76.6	76.0	76.0	76.0	20.3	18.0	do	Fair	
Apr. 28	76.0	74.5	49.8	96.5	21.0	16.0	do	do	36.42
Apr. 29	76.2	74.5	66.4	88.0	18.7	15.0	do	Light showers	
Apr. 30	74.5	74.0	95.0		15.8	14.0	Partly cloudy	Rain	
May 1	75.3	74.0	98.6		16.0	14.7	Cloudy	do	29.39
May 2	75.4	74.5	90.5	94.0	17.5	16.0	Fair	Cloudy	
May 3	76.6	76.0	76.0	99.0	18.0	15.0	do	do	42.68
May 4	76.6	75.3	87.5	93.5	18.5	15.0	do	Rain	14.81
May 5	74.5	73.7	89.2	99.8	19.0	15.5	do	Cloudy	
May 6	75.3	74.0	92.3	89.2	16.4	13.8	Partly cloudy	Partly cloudy	17.22
May 7	74.3	73.5	95.0	95.6	15.3	14.0	Cloudy	Rain	24.96
May 8	74.0	73.5	95.6	94.9	13.5	12.0	do	do	9.83
May 9	73.2	71.5	97.8	95.7	12.2	13.0	Heavy rain	do	
May 10	76.0	75.3	97.0	93.7	13.6	14.2	Cloudy; dense fog	Cloudy; fog	24.34

From the observations recorded in Table X, it is seen that the variations of the radium-emanation content follow fairly definitely the variations of the meteorological conditions. A period of fair weather gives in almost every case comparatively high values for the emanation while heavy rains are always followed by a decrease. The two highest values; namely, those for April 28 and May 3, respectively, were obtained after or during periods of fair weather, while the lowest value, that of May 8, was obtained during a typhoon with strong wind and a heavy downpour of rain.

It is to be regretted that the meteorological data at our command is so meager, but since the nearest weather observatory was 50 kilometers distant we had to depend on the readings of the few instruments which we were able to carry with us. Data on the velocity and direction of the wind would be especially valuable.

SUMMARY

1. Preliminary tests.
   (*a*) As a result of a long series of observations, it has been found that the assumption made by Eve and Satterly, that bubbling air through the cold solution of radium bromide will remove the emanation as rapidly as it is formed, is not justified. By bubbling air through the solution at room temperature, about 27°, only about 80 per cent of the total amount of emanation formed is removed.
   (*b*) For quantities of emanation of the order of magnitude dealt with in the determinations, the charcoal does not become saturated. A phenomenon analogous to saturation manifests itself when the charcoal is packed in a short column. The best distribution of a given weight of charcoal is that obtained in a long tube of small bore.
   (*c*) The coconut charcoal used gave no evidence of containing a trace of radium.
2. The radium-emanation content of the atmosphere of Manila has been determined by the charcoal-absorption method. During a period of eight months, we made twenty-one determinations of the amount of radium emanation per cubic meter of air, the average value, expressed in its radium equivalent, being 82.5×10^{-12} gram. The radium-emanation content is subject to considerable variation, the ratio of the maximum to the minimum being approximately 4 to 1.
3. In order to determine the variation of the radium-emanation content of the atmosphere with altitude, observations by the charcoal-absorption method were taken on Mount Pauai, elevation 2,460 meters. The average value obtained for ten observations was 19.1×10^{-12} gram per cubic meter, as compared with 82.5×10^{-12} gram for Manila. It seems to be fairly conclusive, therefore, that the amount of radium emanation in the atmosphere decreases with altitude. The range of variation of the emanation content was found to be practically the same for Mount Pauai as that given for Manila.
4. For both Manila and Mount Pauai the variation of the amount of radium emanation in the atmosphere has been found to be fairly closely correlated to the changes in the weather. Determinations made during fair weather almost invariably give comparatively high values, while observations taken after or during a period of heavy rains show a decided decrease.

No definite relation has been observed between the variation of the emanation content and a rising or falling barometer. Changes in the humidity, likewise, seem to have no effect on the radioactivity of the atmosphere. The total wind movement is evidently an important factor in determining the variation.

For Manila a decided variation between day and night exposures has been found. The ratio of the average for night exposures to that for day exposures is approximately 2 to 1.

It is our intention to continue observations on this interesting phase of the problem.

ILLUSTRATION

TEXT FIGURE

FIG. 1. Diagram, showing apparatus used in determining the radium emanation in the atmosphere.

BURNING TESTS OF PHILIPPINE PORTLAND CEMENT RAW MATERIALS

By Augustus P. West and Alvin J. Cox

(From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.)

One plate and 3 text figures

The commercial feasibility of manufacturing Portland cement from local raw materials has been an important consideration ever since the American occupation of the Philippine Islands and especially so recently owing to the increase in consumption and cost of cement.

Table I, which is based upon the Annual Reports of the Insular Collector of Customs, shows the quantity, source, and invoice value of Portland cement imported into the Philippine Islands during recent fiscal years.

TABLE I.—*Quantity, origin, and average cost, exclusive of import duty, on board ship at destination, of cements imported into the Philippine Islands.*

Imports from—	Fiscal year 1907.		Fiscal year 1908.		Fiscal year 1909.		Fiscal year 1910.		Fiscal year 1911.		Fiscal year 1912.		Fiscal year 1913.	
	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]	Barrels.[a]	Cost.[b]
United States					215	2.56	50,600	4.72	38,250	4.80	134	6.98	49	
United Kingdom			375	6.50	7,670	3.33	518	3.03	4,030	3.89	273		101	6.23
Germany			11,120	4.58	13,375	4.05	15,230	3.79	8,670	3.90	55,080	2.91	150,900	3.54
France			488	3.90	100	3.40	135	3.73	10	2.28	239	3.90	148	2.44
Italy			1	4.00										
Belgium			8,450	2.98	5,920	1.79	2,920	2.03	2,150	2.00	1,738	1.90	2,410	2.05
Netherlands					500	2.06								
Russia			812	5.19	2,310	5.18	730	5.20	522	3.91	502	3.28		
British East India					320	4.41	15	4.80	9	4.22			704	3.59
French East India							37,500	3.17	69,600	3.38	66,300	3.57	65,490	3.60
Hongkong			135,000	4.28	107,100	3.57	128,300	3.29	212,400	3.32	237,600	2.77	160,100	3.35
Japan			50	2.76	1,750	3.27	1,970	4.02	3,192	4.00	3,709	3.29	13,070	3.58
Austria Hungary									30	4.48				
Spain							90	3.78			64	6.65	63	4.54
China							2,640	3.15	1,612	3.38			712	3.30
Total	[c] 107,000		156,256		139,260		240,648		340,475		365,654		397,861	
Average cost		5.50		4.24		3.55		3.46		3.51		3.61		3.64
Special entries[d]			116,000		110,500		25,730		28,950					
Grand total	107,000		272,256		249,760		266,378		369,425		365,654		397,861	

[a] Barrels 400 pounds (181 kilograms), gross weight.

[b] Invoice valuation in pesos, Philippine currency, per barrel.

[c] Approximate.

[d] Free entries for Manila Railway, Philippine Railway, and United States and Insular Governments.

The import duty of 32 centavos (16 cents United States currency) per 100 kilograms gross weight (about 59 centavos per barrel), landing and importers' charges, lack of competition, etc. have resulted in selling prices which ranged from 4.36 pesos in 1907 to 6.68 pesos in 1912 per barrel for large contracts. The price named in one of the recent contracts awarded by the Bureau of Supply was 5.55 pesos.

A comparison of local prices with those of the United States shows one of the principal causes of the high cost of concrete construction work in the Philippines. According to the report of the United States Geological Survey, the average factory price of gray Portland cement for 1912 was 1.62 pesos per barrel in bulk at the mills and including only the labor cost of packing. During the last two years the average price of cement in the United States, with few exceptions, has been remarkably low, in many instances scarcely above the cost of production, and a selling price of from 1.20 to 1.50 pesos has been customary for years at some of the large plants.[1] Except where natural gas or waste gases from large blast furnaces are available as fuel, a price of 2 pesos per barrel is as low as will yield a reasonable profit. In spite of these comparatively low prices and the fact that cements from the United States can be imported into the Archipelago duty free, the cost of transportation is so great that American cements do not compete in the Philippine market.

In 1905 McCaskey [2] gave analyses of, and called attention to, the unusually high grade of limestone obtained from the Binangonan deposits of Laguna Province, Luzon, and suggested that in all probability it would serve as an excellent material for the purpose of Portland cement manufacture. In 1908 special consideration was given [3] to the volcanic tuff which occurs very abundantly in the neighborhood of Manila as a possible cement siliceous material, and in a later article [4] the possibilities of manufacturing Portland cement from the deposits of shales, clays, and limestones occurring in different parts of the Islands were discussed. After considering the analyses of characteristic specimens of cement materials and the general geological conditions of the localities from which they were obtained, Pratt [5] has pointed out the various locations which seem to be practical

[1] *Cem. & Eng. News* (1913), **25**, 36.
[2] *Sixth Annual Rep. P. I. Min. Bur.* (1905), 20.
[3] Cox, Alvin J., *This Journal, Sec. A* (1908), **3**, 391.
[4] Idem, *This Journal, Sec. A* (1909), **4**, 211.
[5] *Min. Res. P. I. for 1911, Bur. Sci.* (1912), 45.

and desirable for the establishment of a Portland cement plant in the Philippines.

The present paper is a continuation of the work on this problem, special consideration being given to the results obtained from the actual manufacture of Portland cement from some of the raw materials. A thorough study of the commercial and technical considerations involved in the economic production of Portland cement from available local raw materials is a work which will require years of careful study.

A consideration of the physical properties is the first step in the selection of cement raw material. If these are satisfactory, the usual chemical analyses give data from which the composition of the raw cement mixture may be calculated and which assist us to decide whether or not further investigation is necessary. However, such data do not give the chemical combinations of the constituents determined. Silica in the form of quartz does not combine with limestone at a clinkering temperature as readily as when it is in the form of a silicate. Although an ultimate analysis gives the exact silica content of a material, it does not specify whether it is in the crystalline, amorphous, or combined form, a matter of great importance.

A rational analysis may often aid in giving some idea as to the nature of the principal ingredients; such as, clay substance, feldspar, and quartz.[6]

A large amount of experimental work has been done by various investigators in their endeavors to work out a formula to be used as a basis for the calculation of the raw cement mixture as mentioned in a previous paper.[7] Formulæ serve as a basis for the calculation of raw cement mixtures, but they cannot be relied upon to furnish the particular proportion of raw materials which will give the best results in any given instance for they neglect the consideration of such factors as the silica to alumina ratio; the amount of fluxing constituents, such as ferric oxide, alkalies, etc.; and the degree of fineness. A mixture is made according to some formula, burned, the resulting clinker ground, and the product tested according to the

[6] In the case of materials other than kaolinitic clays, such data are of comparatively little importance, because the method of calculating a rational analysis is based on the composition of a typical orthoclase feldspar. The method of rational analysis and determination of soluble silicates suggested by Bleininger [*Bull. Ohio Geol. Sur.* (1904), IV, 3, 67, 119] is slightly different and preferable to the methods recommended in many textbooks on quantitative analysis and ceramic work.

[7] Cox, *loc. cit.*, 214.

usual methods of testing commercial cements. However, the establishment of the best working proportions of any particular raw materials is usually an empirical procedure, and it is frequently necessary to burn several mixtures in order to determine the proper combining proportions and real efficiency of a given material.

If the raw materials have been combined in the most appropriate proportions and properly burned, the resulting clinker, when properly ground, requires no treatment other than the addition of a retarder. If these operations are carried out improperly, further treatment is necessary. The manner in which the degree of pulverization, vitrification, seasoning, and plastering affect the soundness, setting, hardening properties, etc. of cements has been fully treated in the articles of Reibling and Reyes,[8] and results obtained from ground clinker are apt to be misleading unless these factors are taken into consideration. It is necessary to study the cements as well as the raw materials from which they are produced to secure satisfactory results.

RAW MATERIALS

Satisfactory raw materials yield a cement with a magnesia content of less than 3 per cent; a silica to alumina (plus iron oxide) ratio (hydraulic modulus)

$$\left(\frac{\text{per cent silica } (SiO_2)}{\text{per cent alumina } (Al_2O_3) + \text{per cent iron oxide } (Fe_2O_3)} \text{ or } \frac{SiO_2}{R_2O_3}\right)$$

of between 2 and 3.5; a lime to silica, alumina, and iron oxide ratio

$$\left(\frac{\text{per cent lime } (CaO)}{\text{per cent silica } (SiO_2) + \text{alumina } (Al_2O_3) + \text{per cent iron oxide } (Fe_2O_3)} \text{ or } \frac{CaO}{SiO_2 + R_2O_3}\right)$$

between 1.8 and 2.3; and a cementation index

$$\left(\frac{(2.8 \times \text{per cent silica}) + (1.1 \times \text{per cent alumina}) + (0.7 \times \text{per cent iron oxide})}{(\text{per cent lime}) + (1.4 \times \text{per cent magnesia})}\right)$$

between 1.0 and 1.2. The time of setting and ultimate strength of a Portland cement are in inverse proportion to the value of the silica to alumina (plus iron oxide) ratio, and a high lime to silica, alumina, and iron oxide ratio is an indication of a high testing cement.

Theoretically, it is possible to manufacture Portland cement from many different materials which are available in the Philippines. However, the selection of the raw materials which

[8] *This Journal, Sec. A* (1910), 5, 117–142; (1911), 6, 207–252; (1912), 7, 135–191; (1913), 8, 107–125.

are to be used is governed largely by commercial considerations; such as, the ease with which the raw materials may be pulverized, available fuel, location with reference to distributing points, etc. Analysis of the various Philippine materials which may be considered have been segregated by Pratt[9] as given in Tables II and III.

DESCRIPTION OF SAMPLES

1. Miocene limestone from Mount Licos near Camansi coal mine, Danao, Cebu.
2. Miocene limestone (marble), Romblon, Capiz.
3. Miocene limestone, Batan, Albay.
4. Coralline limestone (Pliocene), Cebu, Cebu.
5. Coralline limestone (Pliocene), Danao, Cebu.
6. Coralline limestone (Pliocene), Guimaras Island.

7–14. Coralline marl (Pliocene), Naga, Cebu. Typical of a series of test-hole samples representative of a thickness of from 15 to 30 meters over an area of about 15 hectares.

15. Bedded marl or chalk (Pliocene), Argao, Cebu.

16–17. Argillaceous limestone (Miocene) from near Camansi coal mine, Danao, Cebu.

18. Binangonan limestone, Rizal Province, Luzon.

TABLE II.—*Analyses of calcareous raw materials for cement.*

<table>
<tr><th>Sample No.</th><th>Silica (SiO_2).</th><th>Alumina (Al_2O_3).</th><th>Iron oxide (Fe_2O_3).</th><th>Lime (CaO).</th><th>Magnesia (MgO).</th><th>Alkalies (Na_2O+K_2O).</th><th>Loss on ignition.</th><th>$\frac{SiO_2.}{Al_2O_3+Fe_2O_3.}$</th></tr>
<tr><td>[a]1</td><td>0.36</td><td colspan="2">0.18</td><td>55.62</td><td>------</td><td>------</td><td>43.93</td><td>------</td></tr>
<tr><td>[a]2</td><td>0.10</td><td colspan="2">0.17</td><td>55.23</td><td>0.45</td><td>------</td><td>43.80</td><td>------</td></tr>
<tr><td>[a]3</td><td>0.97</td><td>0.56</td><td>0.36</td><td>53.86</td><td>0.19</td><td>------</td><td>43.18</td><td>------</td></tr>
<tr><td>[b]4</td><td>1.31</td><td colspan="2">3.90</td><td>52.01</td><td>0.63</td><td>------</td><td>------</td><td>------</td></tr>
<tr><td>[b]5</td><td>2.61</td><td colspan="2">2.23</td><td>52.85</td><td>0.88</td><td>------</td><td>------</td><td>------</td></tr>
<tr><td>[b]6</td><td>6.28</td><td colspan="2">4.33</td><td>45.76</td><td>2.70</td><td>------</td><td>------</td><td>------</td></tr>
<tr><td>[b]7</td><td>11.12</td><td colspan="2">4.28</td><td>45.65</td><td>------</td><td>------</td><td>------</td><td>2.6</td></tr>
<tr><td>[b]8</td><td>14.10</td><td colspan="2">5.77</td><td>43.27</td><td>------</td><td>------</td><td>------</td><td>2.4</td></tr>
<tr><td>[b]9</td><td>11.57</td><td colspan="2">4.62</td><td>46.25</td><td>------</td><td>------</td><td>------</td><td>2.5</td></tr>
<tr><td>[b]10</td><td>12.62</td><td colspan="2">5.75</td><td>43.36</td><td>------</td><td>------</td><td>------</td><td>2.2</td></tr>
<tr><td>[c]11</td><td>9.43</td><td colspan="2">4.02</td><td>47.53</td><td>------</td><td>------</td><td>------</td><td>2.3</td></tr>
<tr><td>[c]12</td><td>10.28</td><td>0.63</td><td>3.28</td><td>45.96</td><td>------</td><td>------</td><td>------</td><td>2.9</td></tr>
<tr><td>[c]13</td><td>8.37</td><td>0.22</td><td>3.25</td><td>49.84</td><td>1.02</td><td>------</td><td>------</td><td>2.4</td></tr>
<tr><td>[c]14</td><td>11.99</td><td>0.57</td><td>2.90</td><td>45.69</td><td>------</td><td>------</td><td>------</td><td>3.5</td></tr>
<tr><td>[b]15</td><td>8.93</td><td colspan="2">6.45</td><td>44.35</td><td>2.70</td><td>------</td><td>------</td><td>1.4</td></tr>
<tr><td>[a]16</td><td>29.00</td><td>11.38</td><td>5.35</td><td>26.25</td><td>0.65</td><td>1.98</td><td>23.00</td><td>1.7</td></tr>
<tr><td>[a]17</td><td>24.02</td><td>7.49</td><td>2.00</td><td>33.88</td><td>2.12</td><td>------</td><td>28.25</td><td>2.5</td></tr>
<tr><td>[d]18</td><td>1.12</td><td>0.08</td><td>0.07</td><td>53.78</td><td>1.19</td><td>0.77</td><td>43.31</td><td>------</td></tr>
</table>

[a] Cox, Alvin J., *This Journal, Sec. A* (1909), 4, 211.

[b] Analyzed by Forrest B. Beyer, Bureau of Science.

[c] Analyzed by T. Dar Juan, Bureau of Science.

[d] Analyzed by Bureau of Government Laboratories. Sample contains 0.06 per cent FeO not included in Fe_2O_3 column.

[9] *Min. Res. P. I. for 1911, Bur. Sci.* (1912), 90.

DESCRIPTION OF SAMPLES

1. Shale from Batan Island.
2–5. Shale from Batan Island. Samples from drilled test holes.
6. Shale from near Camansi Coal Mine, Danao, Cebu.
7. Shale from near Camansi Coal Mine, Danao, Cebu.
8. Shale from Tigbauan, Iloilo.
9. Shale from Cantaingan, Masbate.
10. Alluvial clay from Malinta, Bulacan.
11. Clay from Binangonan, Rizal.
12. Alluvial clay from Pasig River near Manila.
13. Clay from near Camansi Coal Mine, Danao, Cebu.
14. Alluvial clay from Pandan River, Naga, Cebu. Representative of drilled test-hole samples.
15. Alluvial clay from mangrove swamp, Loay, Bohol. Sample from drilled hole.
16. Volcanic tuff. From vicinity of Manila.
17. Schist from Romblon.
18–20. Graywacke, Naga, Cebu. Typical of a series of samples from drilled test holes over an area of 16 hectares.
21. Rhyolite from Cebu.

TABLE III.—*Analysis of argillaceous raw material for Portland cement.*

Sample No.	Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia. (MgO).	Alkalies (Na_2O+K_2O).	Loss on ignition.	$\frac{SiO_2}{Al_2O_3+Fe_2O_3}$
[a] 1	35.02	13.98	6.01	17.44	2.84	1.97	17.50	1.8
[b] 2	52.84	28.50		1.98	1.82	3.10	--------	1.9
[b] 3	46.31	26.68		--------	--------	--------	--------	1.6
[b] 4	51.88	26.13		--------	--------	--------	--------	2.0
[b] 5	55.97	30.09		--------	--------	--------	--------	1.9
[a] 6	53.25	24.11	9.03	0.80	2.22	--------	8.72	1.6
[d] 7	33.74	16.48		--------	--------	--------	--------	2.0
[d] 8	37.84	21.07		--------	--------	--------	--------	1.8
[d] 9	49.08	27.23		--------	--------	--------	--------	1.8
[e] 10	47.77	[c] 18.73	7.19	1.78	2.06	1.86	13.84	1.8
[e] 11	50.81	20.54	7.37	0.91	1.05	--------	8.14	1.8
[e] 12	52.83	[c] 21.01	8.40	4.04	2.58	2.68	9.08	1.8
[a] 13	60.17	22.65	4.66	0.31	1.85	--------	6.35	2.2
14	60.50	26.50		2.00	--------	--------	8.45	2.3
[d] 15	37.13	20.04		--------	--------	--------	--------	1.9
[f] 16	59.27	17.06	5.06	3.37	1.52	6.12	6.42	2.7
[a] 17	80.12	12.56	1.15	0.12	0.48	3.69	1.94	5.8
[b] 18	68.10	14.50	2.70	3.07	0.94	--------	--------	4.0
[b] 19	66.14	12.75	0.96	3.43	0.53	--------	--------	4.8
[b] 20	69.16	14.06		--------	--------	--------	--------	4.9
[g] 21	76.15	14.93	0.27	1.40	1.24	5.65	--------	5.0

[a] Cox, Alvin J., *This Journal, Sec. A* (1909) **4**, 211.
[b] Analyzed by T. Dar Juan.
[c] Includes titanium oxide (TiO_2).
[d] Analyzed by Beyer.
[e] Cox, Alvin J., *This Journal, Sec. A* (1907), **2**, 413.
[f] Cox, Alvin J., *This Journal, Sec. A* (1908), **3**, 404.
[g] Ferguson, Henry G., *This Journal, Sec. A* (1907), **2**, 407.

The analyses show that materials which are more or less suited to the manufacture of Portland cement are widely distributed. Pratt[10] gives the following list of localities, each of which present in some degree the characteristics essential to a cement manufacturing site.

1. Island of Cebu.
2. Vicinity of Manila.
3. Island of Batan, Albay Province.
4. Island of Masbate, Sorsogon Province.
5. Island of Polillo, Tayabas Province.
6. Vicinity of Bani, Pangasinan Province.
7. Island of Romblon, Capiz Province.
8. Vicinity of Balayan, Batangas Province.
9. Vicinity of Iloilo, Iloilo Province.
10. Vicinity of Loay, Bohol Province.

A complete investigation of the Cebu materials is now being made by Messrs. Reibling and Reyes. We have burned a few mixtures of pure limestone combined with clays obtained from the Mount Licos region, Cebu, but since Manila is the metropolis and principal distributing point in the Islands we have confined our attention principally to the investigation of volcanic tuff and Binangonan limestone which are the cement raw materials available in the vicinity.

EXPERIMENTAL

In our experiments the materials were thoroughly mixed. Each mixture was moistened with water, made up into a dough-like mass, rolled out with a rolling pin to a thickness of 10 millimeters, and cut into bricks, the dimensions of which were about 25 by 10 by 10 millimeters. The molded bricks were then dried in an air bath at 100°, after which they were placed in bottles preparatory to burning. The raw materials and finished products in all cases except where otherwise specified were ground to pass a sieve having 120 meshes to the inch.

Experimental burnings have been made in both rotary and stationary kilns, but considerable difficulty was experienced in obtaining an experimental kiln which would give a sufficiently large quantity of noncontaminated, well-burned clinker. A kiln must be so constructed that the escape of the heat generated from the fuel will be hindered as much as possible if a high temperature is required.

Campbell,[11] in his experimental cement work, used a small

[10] Loc. cit., 91.
[11] *Journ. Am. Chem. Soc.* (1902), 24, 248.

rotary kiln made of an iron pipe, 8 inches in diameter and 32 inches long. The lining material consisted of hard-burned magnesite. The furnace was rotated by means of a 0.5-horsepower motor with a speed of 1 revolution per one minute and twenty-five seconds and was heated by means of a Hoskins gasoline burner to which gasoline was supplied at about 50 pounds' pressure. Temperature measurements were made by a Le Chatelier thermocouple connected with a reflecting galvanometer. In one series of experiments the following temperatures were recorded: Temperature of hottest section, 1,630°; temperature at six inches from hot end, 1,500°; temperature at feed end, 1,200°.

We constructed a kiln like that of Campbell except that it was 1.11 meters in length. The apparatus failed to produce satisfactory results, and we were unable to obtain a uniformly well-sintered clinker, principally on account of the difficulty in hindering the escape of heat. A large amount of heat was continually reflected toward the burner, and escaped at the opening where the clinker emerged. Cement obtained from our rotary contained considerable free lime, and although a few assorted specimens of clinker came within the specifications of initial and final-set and boiling tests, yet the tensile strengths of neat and sand-mortar-briquettes were too low to pass specifications. The bricks of unplastic volcanic tuff in the course of the rough journey through a rotary were ground to a powder, some of which was blown out of the feed end.[12]

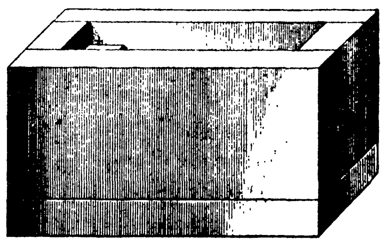

FIG. 1. Cement furnace, exterior.

The usual type of stationary kiln used for experimental cement burning consists essentially of an updraft kiln.[13] A temperature of 1,370° (Seger cone No. 12) is obtained without difficulty. In a stationary upright kiln the cement mixture and fuel are fed usually in alternate layers. However, this method of burning produces clinker contaminated with the fuel ash which changes the calculated composition, and in such a furnace it is almost impossible to heat a raw cement mixture uniformly for a given length of time.

[12] We were able to overcome this to a large extent by molding our cubes with an agar-agar solution instead of water, which increased the plasticity of the tuff and rendered the dried blocks considerably more durable.

[13] *Bull. Ohio State Geol. Surv.* (1904), IV, 3, 244.

A design of a furnace which we have found to be satisfactory is shown in text figures 1, 2, and 3. Fig. 1 represents the empty furnace. Fig. 2 is a cross section of the furnace showing small blocks of the raw mixture piled one upon the other. The top is arranged in such a manner that the lower part of the chimney instead of being straight has the form of a staircase. This is accomplished by cutting the bricks which cover the furnace in such a way that they rest on the sides of the furnace and project or hang in the interior. Fig. 3 shows the furnace covered and ready for use. The furnace was fired by means of a Cary hydrocarbon burner with gasoline under 40 pounds' air pressure supplied by an electric motor-driven compressor. The equipment was supplied with the necessary valves and pressure gauges so that the exact pressure was always known and was under control. The hydrocarbon burner[14] is placed directly against the furnace opening, in order to throw all the heat generated into it. At the hot end of the kiln, there is no opening for the clinker to emerge as in a laboratory rotary, and consequently practically all the heat generated is thrown directly into the kiln and reflected back and forth around the pile of cement mixture in the interior. The material is burned uniformly to a hard, black clinker which under a magnifying glass shows no white spots indicating free lime. Plate

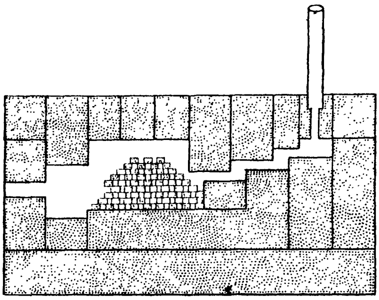

FIG. 2. Cross section of cement furnace, showing small blocks of the raw mixture.

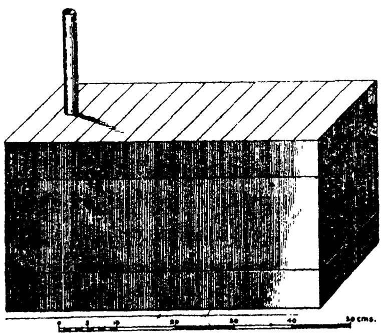

FIG. 3. The furnace covered and ready for use.

[14] Since a hydrocarbon burner does not work well until a temperature of low redness has been obtained, it is desirable to place a piece of wood about 7 centimeters square inside the furnace at the opening directly in front of the burner. This enables the burner to draw well, and prevents it from striking back. After about thirty minutes the wood is completely burned and the interior of the furnace red hot. A piece of asbestos containing a hole exactly the size of the opening of the burner is placed between the furnace and the burner to protect the latter from the heat.

I, fig. 2, is from a photograph of characteristic samples of clinker produced in this manner. When the blocks of raw material have been sufficiently vitrified and the furnace has cooled, the black clinker can easily be removed by gently tapping the clusters of blocks which are sintered together. A furnace of the dimensions indicated in the diagrams yields about 800 grams of well-burned clinker in one burning.

The suitability of our horizontal stationary kiln for burning cements was demonstrated by burning therein an average sample of raw cement mixture obtained from a cement company whose well-burned product meets all specified requirements. Seger cones supported on platinum were placed in the furnace behind the mixture out of the direct path of the flame. The mixture was then burned to a clinker in the manner above described, after which it was pulverized and tested. The temperature recorded by the Seger cones was 1,500°. Analyses recorded in Table IV show the composition of this mixture and of the cement obtained from it.

TABLE IV.—*Analysis of the cement company raw mixture and cement obtained from it.*

Constituent.	Analysis of mixture.	Analysis of cement.
	Per cent.	*Per cent.*
Silica (SiO_2)	14.02	20.76
Alumina (Al_2O_3)	5.93	12.50
Ferric oxide (Fe_2O_3)	0.87	
Lime (CaO)	42.12	64.80
Magnesia (MgO)	1.81	2.14
Volatile	34.99	---------
Total	99.74	100.20

The silica to alumina (plus iron oxide) ratio of the mixture is 2.06.
The cementation index of the mixture is 1.04.
The cementation index of cement is 1.06.

Pats of this nonaërated neat cement [15] after undergoing the boiling test proved to be unusually sound and adhered to the glass plates with great tenacity. As is well known the ordinary commercial brands of cement after undergoing the boiling test do not adhere very firmly to the glass plates. The specific gravity was 3.20, and the tensile strength of standard, 1 : 3

[15] It was properly burned, so that no aëration was necessary to carbonate the free lime.

Ottawa-sand mortar for seven and twenty-eight days was 415 and 460 pounds, respectively, per square inch.

A high-limed mixture requires a high-burning temperature, and it is expedient to make the first trial burning with a low-limed and heavily clayed mixture. It was the intention to follow our work on low-limed mixtures with an investigation of those high in lime, but we have been prevented from doing this by the pressure of other work and so present such results as are completed.

CEBU RAW CEMENT MATERIALS

Danao clay.—The suitability of this material for the manufacture of Portland cement has already been pointed out,[16] and it was desired to confirm this by a burning test. A composite sample of specimens obtained from the Mount Licos region near Danao, Cebu, was prepared by grinding and sifting to a fineness of 120 mesh. No rational analyses were made as the material was free from grit. In Table V is given the ultimate analysis of this material.

TABLE V.—*Analysis of Danao clay.*

Constituent.	Per cent.
Silica (SiO_2)	58.35
Alumina (Al_2O_3)	20.72
Iron (Fe_2O_3)	7.85
Lime (CaO)	1.47
Magnesia (MgO)	1.97
Volatile matter	10.31
Total	100.67

The calculation of the combining proportions of a pure limestone and Danao clay cement mixture in accordance with the formula ($2.8CaO{\cdot}SiO_2+2CaO{\cdot}R_2O_3$) would be as follows:

$58.35 \times 2.60 = 151.71$ parts calcium oxide required by silica in 100 parts clay.

$20.72 \times 1.10 = 22.79$ parts calcium oxide required by alumina in 100 parts clay.

$7.85 \times 0.70 = 5.49$ parts calcium oxide required by ferric oxide in 100 parts clay.

179.99 parts calcium oxide required by 100 parts clay.

$1.47 + (1.97 \times 1.40) = 4.23$ parts calcium oxide equivalent to calcium and magnesium in 100 parts clay.

$179.99 - 4.23 = 175.76$ parts calcium oxide to be added to 100 parts clay.

56 parts calcium oxide available in 100 parts pure calcium carbonate.

$175.76 / 56 = 3.14$ parts calcium carbonate required by 1 part clay.

[16] Cox, *loc. cit.*, 218.

Twelve per cent less calcium carbonate than demanded by the formula would require 2.76 parts calcium carbonate to 1 part of clay. The results of combining pure limestone and Danao clay according to this calculation are given in Table VI.

TABLE VI.—*Calculation of Danao clay-cement raw mixture.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).[a]	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O etc.).
Figures represent parts of the material by weight.							
Limestone	276.00				154.50		121.40
Clay	100.00	58.35	20.72	7.85	1.50	1.97	10.31
Unburned	376.00	58.35	20.72	7.85	156.00	1.97	131.70
Volatile	131.70						
Burned	244.30	58.35	20.72	7.85	156.00	1.97	
Calculated composition in percentage.							
Mixture	100.16	15.52	5.51	2.09	41.49	0.52	35.03
Clinker	100.24	23.88	8.48	3.21	63.86	0.81	

[a] Estimating all of the iron as ferric oxide.

Silica to alumina (plus iron oxide) ratio in the mixture is 2.04.
Lime to silica, alumina, and iron oxide ratio in the mixture is 1.8.
Cementation index of the mixture is 1.21.

The mixture was burned to a hard, black clinker. The clinker was ground and tested in the usual manner with the results shown in Table VII.

TABLE VII.—*Physical examination of cement.*

Specific gravity.	Soundness.		Initial set.	Final set.	Tensile strength in pounds per square inch.			
					Neat cement.		1 cement : 3 sand.	
	5 hours.	28 days.			7 days.	28 days.	7 days.	28 days.
			Hrs. mins.	*Hrs. mins.*				
3.25	Sound	Sound	1.35	2.5	529	608	276	402

The above values represent the average of 6 determinations. The high specific gravity is characteristic of a sound cement. While the tensile strengths obtained are not high owing to the

low lime content, they fulfill specifications.[17] Indeed, it was not anticipated that such a mixture would give a passable cement, but a low-limed mixture was chosen to get conditions under perfect control. No difficulty was experienced in working with this material, and the experiment shows that Portland cement can be manufactured satisfactorily from it. Higher tensile strengths could be obtained by working out the most suitable proportions in which to combine the raw materials.

Volcanic tuff.—The chemical compositions of several samples of Philippine tuffs have been published.[18] Andesitic volcanic tuff borders the Pasig River near Guadalupe between Manila and Laguna de Bay.[19]

The ultimate analysis of this tuff indicates its adaptability to the manufacture of cement, and we desired to confirm this by actual manufacture. Its physical characteristics are somewhat variable; however, with proper care in preparing and combining the raw mixture any difficulty arising from this source could probably be eliminated.

The sample of tuff used for these experiments was collected from a bluff about 25 meters high on the shore of the Pasig River. Specimens were taken at intervals of about 1 meter beginning at the bottom and proceeding somewhat diagonally to the top, so that the sample represents the different grades of fine, coarse, and medium as they naturally occur in the deposit. The sample was crushed, mixed, and ground. Table VIII gives the analytical data pertaining to the composite sample used for these experiments.

[17] The standard Portland cement specifications adopted by the United States Government and which apply to the Philippine Islands require the following figures for tensile strengths in pounds per square inch.

Neat cement.		1 cement : 3 sand.	
7 days.	28 days.	7 days.	28 days.
500	600	200	275

[18] Cox, Alvin J., *This Journal,* Sec. A (1908), 3, 404.

[19] This is a water-laid formation. Adams [*This Journal, Sec. A* (1910), 5, 73] states, "It is usually clearly stratified and exhibits beds of variable thickness. In places it grades into clayey, somewhat shaley beds and it occasionally contains a conglomeratic phase, especially near the foothills of the eastern cordillera. It is probable that a large part of the tuff deposits was thrown out by the volcanoes of the southwestern region, but certainly some sediments must have been derived from the adjacent cordillera."

TABLE VIII.—*Ultimate analysis of volcanic tuff.*

Constituent.	Per cent.
Silica (SiO_2)	[a] 56.36
Alumina (Al_2O_3)	19.53
Ferric oxide (Fe_2O_3)	6.97
Lime (CaO)	4.31
Magnesia (MgO)	1.70
Alkalies (Na_2O+K_2O)	1.99
Volatile matter	9.30
Total	100.16

[a] Soluble silicates = 18.50 per cent.

The relatively large percentage of soluble silicates is a desirable feature. A rational analysis indicated the presence of about 5 per cent of free silica. It is probable that the result gives an erroneous impression for materials of this class and that there is only a very small amount of free silica actually present.[20]

A mixture prepared according to the method of calculation from the formula described under the discussion of Danao clay would consist of 1 part of tuff combined with 2.968 parts of pure limestone. Two mixtures containing 2 and 5 per cent less limestone, respectively, were prepared. The calculations of these are given in Tables IX and XI, respectively.

TABLE IX.—*Calculation of volcanic tuff raw mixture containing 2.29 per cent less pure limestone than required by the formula.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
Figures represent parts of the material by weight.							
Limestone	209.00				162.40		127.60
Tuff	100.00	56.36	19.53	6.97	4.30	1.70	9.30
Unburned	390.00	56.36	19.53	6.97	166.70	1.70	136.90
Volatile	136.90						
Burned	251.10	56.36	19.53	6.97	166.70	1.70	
Calculated composition in percentage.							
Mixture	99.52	14.45	5.01	1.79	42.74	0.43	35.10
Clinker	99.27	22.27	7.72	2.75	65.86	0.67	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.13.
The lime to silica, alumina, and iron oxide ratio in the mixture is 2.01.
Cementation index of the mixture is 1.09.

[20] *Cf.* footnote 7.

The ground clinker from the burned mixture gave the following results:

TABLE X.—*Physical examination of cement from volcanic tuff raw mixture containing 2.29 per cent less pure limestone than required by the formula.*

Fineness.		Specific gravity.	Soundness.		Initial set.	Final set.	Tensile strength in pounds per square inch.			
							Neat cement.		1 cement: 3 sand.	
200 mesh.	100 mesh.		5 hours.	28 days.			7 days.	28 days.	7 days.	28 days.
					Hrs. min.	*Hrs. min.*				
89.6	99.8	3.19	Sound	Sound	55	1 15	776	800	370	437

TABLE XI.—*Calculation of volcanic tuff raw mixture containing 5.22 per cent less pure limestone than required by the formula.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
Figures represent parts of the material by weight.							
Limestone	281.40				156.53		123.77
Tuff	100.00	56.36	19.53	6.97	4.31	1.70	9.30
Unburned	381.30	56.36	19.53	6.97	161.84	1.70	133.07
Volatile	133.07						
Burned	248.23	56.36	19.53	6.97	161.84	1.70	
Calculated composition in percentage.							
Mixture	99.48	14.78	5.12	1.83	42.43	0.44	34.88
Clinker	99.26	22.71	7.87	2.81	65.19	0.68	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.13.
The lime to silica, alumina, and iron oxide ratio in the mixture is 1.95.
The cementation index of the mixture is 1.12.

The ground clinker from the burned mixture gave the following results:

TABLE XII.—*Physical examination of cement from volcanic tuff raw mixture containing 5.22 per cent less pure limestone than required by the formula.*

Fineness.		Specific gravity.	Soundness.		Initial set.	Final set.	Tensile strength in pounds per square inch.			
							Neat cement.		1 cement: 3 sand.	
200 mesh.	100 mesh.		5 hours.	28 days.			7 days.	28 days.	7 days.	28 days.
					Hrs. mins.	*Hrs. mins.*				
95.0	99.6	3.16	Sound	Sound	30	40	430	620	379	423

The data for the first mixture are very satisfactory. The figures showing the tensile strength of neat cement for the second mixture are somewhat lower.

A few other mixtures containing still less calcium carbonate were prepared; namely, 9, 12, and 17 per cent less than required by the formula, in order to gain a definite idea as to the most favorable proportions in which to combine the tuff and limestone. The mortar strengths of the cement obtained from these are recorded in Table XIII.

TABLE XIII.—*Tensile strength of cement from volcanic tuff raw mixtures.*

Per cent less calcium carbonate than required by the formula.	Proportions (parts by weight).		Tensile strength in pounds per square inch.	
			1 cement : 3 sand.	
	Tuff.	Limestone ($CaCO_3$).	7 days.	28 days.
9	1	2.697	226	333
12	1	2.610	214	313
17	1	2.465	169	270

From our experimental results it is evident that Portland cement can be prepared from mixtures of volcanic tuff and pure limestone. The mixture that contained 2.29 per cent less limestone than is required by the formula gave the most favorable results.

One experiment was carried on in order to determine the influence of mixing clay with volcanic tuff. Intimate mixtures of 1 part of Danao clay with 2.83 parts of pure limestone (10 per cent less than required by the formula) and of volcanic tuff

with 2.61 parts of pure limestone (12.06 per cent less than required by the formula) were prepared. Next, these two mixtures were combined in the proportion of 2 parts of tuff to 1 part of clay. Table XIV gives calculations of the combined raw mixture.

TABLE XIV.—*Calculation of combined mixture of Danao clay and volcanic tuff.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Ironoxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
Figures represent parts of the material by weight.							
Tuff mixture	198.98	31.22	10.82	3.86	83.38	0.94	68.76
Clay mixture	100.15	15.23	5.41	2.05	41.75	40.51	35.20
Unburned	299.13	46.45	16.23	5.91	125.13	1.45	103.96
Volatile	103.96						
Burned	195.17	46.45	16.23	5.91	125.13	1.45	
Calculated composition in percentage.							
Mixture	99.98	15.53	5.43	1.98	41.79	0.48	34.77
Clinker	99.92	23.80	8.31	3.03	64.04	0.74	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.10.
The lime to silica, alumina, and iron oxide ratio in the mixture is 1.82.
Cementation index of the mixture is 1.20.

The ground clinker from the burned mixture gave the following results:

TABLE XV.—*Physical examination of cement from Danao clay and volcanic tuff combination.*

Specific gravity.	Soundness and set.				Tensile strength in pounds per square inch.			
	Soundness.		Initial set.	Final set.	Neat cement.		1 cement : 3 sand.	
	5 hours.	28 days.			7 days.	28 days.	7 days.	28 days.
			Hrs. mins.	*Hrs. mins.*				
3.28	Sound	Sound	2 30	8 50	510	640	239	309

The results indicated that there is no advantage, commensurate with the additional labor and expense involved, in using a mixture rather than tuff alone as siliceous material.

It is easier to obtain a satisfactory clinker from a natural cement rock (argillaceous limestone) than from mixtures of limestone with siliceous materials, because in the former case the materials are already chemically combined. Therefore, it probably would be still less difficult to burn mixtures of tuff and impure limestone, such as would actually be used in cement manufacture, than mixtures of tuff and pure limestone, because the impure carbonate already contains a certain amount of combined silicates.

The most available limestone in the vicinity of Manila is that from Binangonan. If tuff were utilized for the commercial manufacture of cement, it would probably be preferable to locate the plant on the Pasig River near Manila adjacent to the tuff deposit and transport the limestone to the mill.

The calculation of a cement mixture of volcanic tuff and Binangonan limestone would be as follows:

According to the calculation in accordance with the formula described under the discussion of Danao clay, 100 parts tuff would require 166.21 parts calcium oxide. The remainder of the calculation would be as follows:

$1.19 \times 1.4 =$	1.67	
	53.78	
	55.45	parts calcium oxide equivalent to calcium oxide plus magnesium oxide in 100 parts Binangonan limestone.[21]
$1.12 \times 2.60 =$	2.91	
$0.08 \times 1.10 =$	0.09	
$0.07 \times 0.70 =$	0.05	
$0.06 \times 0.78 =$	0.05	
	3.10	parts calcium oxide equivalent to unavailable elements in 100 parts limestone.
$55.45 - 3.10 =$	52.35	parts calcium oxide available in 100 parts limestone.
$166.21 / 52.35 =$	3.175	parts Binangonan limestone required by 1 part tuff.

The Binangonan limestone and volcanic tuff combined according to this calculation will yield the products shown in Table XVI.

[21] Based on analysis given in No. 18, Table II.

TABLE XVI.—*Calculation of volcanic tuff and Binangonan limestone cement mixture.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
Numbers give parts of the material by weight.							
Limestone	317.50	3.56	0.25	0.22	170.70	3.78	137.50
Tuff	100.00	56.36	19.53	6.97	4.30	1.70	9.30
Unburned	417.50	59.92	19.78	7.19	175.00	5.48	146.80
Volatile	146.80						
Burned	270.70	59.92	19.78	7.19	175.00	5.48	
Calculated composition in percentage.							
Mixture	99.20	14.35	4.74	1.72	41.92	1.31	35.16
Clinker	98.77	22.13	7.31	2.66	64.65	2.02	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.22.
The lime to silica, alumina, and iron oxide ratio in the mixture is 2.01.
The cementation index of the mixture is 1.06.

A sample of Binangonan limestone was obtained from the neighborhood of San Guillermo, an abandoned barrio near the town of Teresa in Rizal Province. San Guillermo is situated at an elevation of approximately 200 meters, and is about 5 kilometers inland from the town of Darangan on Laguna de Bay. The sample collected was crushed, thoroughly mixed, and ground. The analysis of this sample is given in Table XVII.

TABLE XVII.—*Analysis of Binangonan limestone from San Guillermo, Rizal, Province, Luzon.*

Constituent.	Per cent.
Silica (SiO_2)	2.33
Alumina (Al_2O_3)	0.44
Iron oxide (Fe_2O_3)	0.39
Lime (CaO)	53.40
Magnesia (MgO)	0.74
Volatile matter	42.67
Total	99.97

A mixture prepared according to the method of calculation from the formula described above would consist of 1 part of tuff combined with 3.49 parts of Binangonan limestone. Two mixtures containing 5 and 10 per cent less Binangonan limestone,

respectively, were prepared. The calculation of these are given in Tables XVIII and XX, respectively.[22]

TABLE XVIII.—*Calculation of volcanic tuff raw mixture containing 5 per cent less Binangonan limestone than required by the formula.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Calcium oxide (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
The numbers give parts of the materials by weight.							
Limestone	331.50	7.72	1.46	1.29	177.00	2.45	141.40
Tuff	100.00	56.36	19.53	6.97	4.30	1.70	9.30
Unburned	431.50	64.08	20.99	8.26	181.30	4.15	150.70
Volatile	150.70						
Burned	280.80	64.08	20.99	8.26	181.30	4.15	
Calculated composition in per cent.							
Mixture	99.52	14.85	4.86	1.91	42.02	0.06	34.92
Clinker	99.28	22.82	7.47	2.94	64.57	1.48	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.19.
The lime to silica, alumina, and iron oxide ratio in the mixture is 1.94.
The cementation index of the mixture is 1.11.

The ground clinker from the burned mixture gave the following results:

TABLE XIX.—*Physical examination of cement from volcanic tuff raw mixture containing 5 per cent less San Guillermo, Binangonan, limestone than required by the formula.*

Tensile strength in pounds per square inch.			
Neat.		Mortar 1:3.	
7 days.	28 days.	7 days.	28 days.
562	650	359	546

[22] Even in the most uniform quarries, the raw materials will vary in composition from time to time and the relative proportions of cement raw mixture must be readjusted. When a constant value for the percentage of lime in the mixture has been chosen, the adjustment can be readily accomplished by arranging a table with the limits of the percentage of lime in the limestone and siliceous cement materials, respectively, as abscissa and ordinate, so that when the percentages are known the combining proportion to give a mixture with a fixed lime content can be at once read by noting the point of intersection of the corresponding coördinates.

TABLE XX.—*Calculation of volcanic tuff raw mixture containing 10 per cent less San Guillermo, Binangonan, limestone than required by the formula.*

	Total.	Individual constituents.					
		Silica (SiO_2).	Alumina (Al_2O_3).	Iron oxide (Fe_2O_3).	Calcium oxide (CaO).	Magnesia (MgO).	Volatile (CO_2, H_2O, etc.).
The numbers give parts of the materials by weight.							
Limestone	314.10	7.32	1.38	1.22	167.70	2.32	134.00
Tuff	100.00	56.36	19.53	6.97	4.30	1.70	9.30
Unburned	414.10	63.68	20.91	8.19	172.00	4.02	143.30
Volatile	143.30						
Burned	270.80	63.68	20.91	8.19	172.00	4.02	
Calculated composition in per cent.							
Mixture	99.52	15.38	5.05	1.98	41.54	0.97	34.60
Clinker	99.26	23.52	7.72	3.02	63.52	1.48	

The silica to alumina (plus iron oxide) ratio in the mixture is 2.19.
The lime to silica, alumina, and iron oxide ratio in the mixture is 185.
The cementation index of the mixture is 1.16.

The ground clinker from the burned mixture gave the following results:

TABLE XXI.—*Physical examination of cement from volcanic tuff raw mixture containing 10 per cent less San Guillermo, Binangonan, limestone than required by the formula.*

Tensile strength in pounds per square inch.			
Neat.		Mortar 1:3.	
7 days.	28 days.	7 days.	28 days.
715	715	275	374

These raw materials in so far as composition is concerned appear to be well adapted to the manufacture of Portland cement, for both mixtures produced cement above that required by the standard specifications.

For purposes of comparison with the above cement mixtures, we give the standard slurry mixture of the Sandusky Portland Cement Company, Ohio,[23] as follows:

[23] Hillebrand, W. F., *Journ. Am. Chem. Soc.* (1903), 25, 1186.

TABLE XXII.—*Standard slurry mixture of the Sandusky Portland Cement Company.*

Constituent.	Per cent.
Silica (SiO_2)	13.51
Alumina (Al_2O_3)	3.50
Iron oxide (Fe_2O_3)	1.43
Alumina plus iron oxide (R_2O_3)	4.93
Calcium oxide (CaO)	40.84
Magnesia (MgO)	0.75
Sulphuric anhydride (SO_3)	1.43
Loss on ignition	37.50
$\frac{SiO_2}{R_2O_3}$	2.81
$\frac{CaO}{SiO_2+R_2O_3}$	2.21
Cementation index	1.02

This approximately corresponds to the composition of actual mixture given by Eckel,[24] which lie approximately within the limits indicated by the following analyses:

TABLE XXIII.—*Composition of actual cement mixtures.*

Constituent.	(1) Per cent.	(2) Per cent.
Silica (SiO_2)	14.94	12.92
Alumina (Al_2O_3)	2.66	4.83
Iron oxide (Fe_2O_3)	1.10	1.77
Alumina plus iron oxide (R_2O_3)	3.66	6.60
Calcium oxide (CaO)	42.34	42.30
Magnesia (MgO)	2.21	2.08
Carbon dioxide (CO_2)	35.68	35.49
Water		
$\frac{SiO_2}{R_2O_3}$	4.08	1.96
$\frac{CaO}{SiO_2+R_2O_3}$	2.28	2.17
Cementation index	1.00	0.945

It was our intention to extend and expand this investigation, but the pressure of other work and the departure of one of us on an extended leave of absence induce us to present the results now completed.

[24] Cements, Limes, and Plasters. John Wiley and Sons, New York (1909), 394.

SUMMARY

The silica to alumina (plus iron oxide) ratio, the lime to silica, alumina, and iron oxide ratio, and the cementation index of the mixtures of Philippine cement raw materials which we have used are entirely within the limits of technical mixtures which have successfully been used elsewhere. The cement produced from these materials was sound and of high specific gravity and tensile strength. The results which we have obtained show that the materials which we have investigated are well adapted to the manufacture of Portland cement.

ILLUSTRATIONS

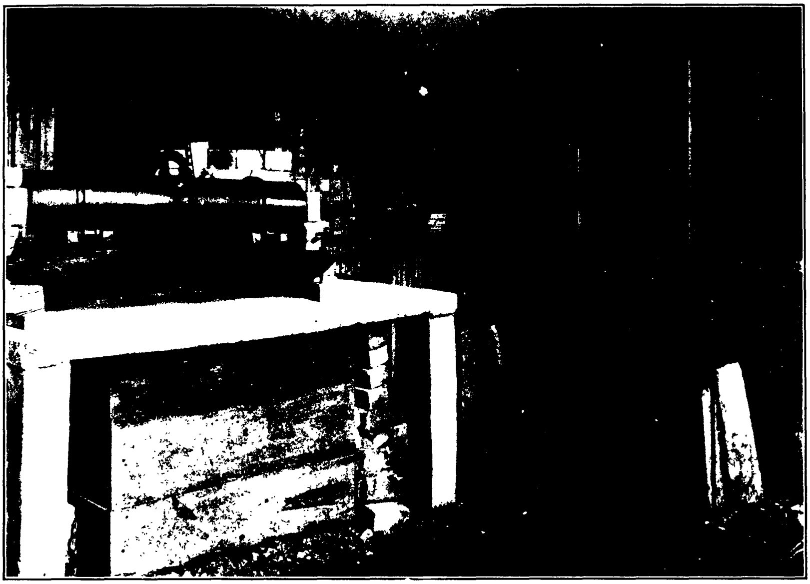

Fig. 1. Vertical and rotary cement kilns and air compressor manufactured in the Bureau of Science.

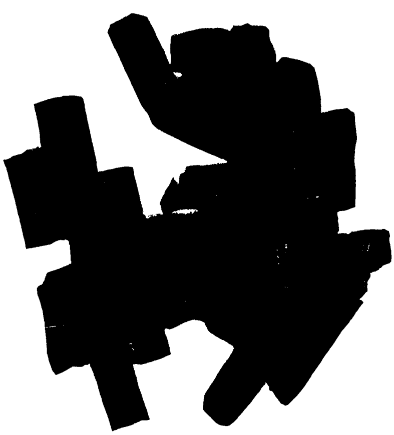

Fig. 2. Perfectly sintered Portland cement clinker made from available Philippine raw materials and burned in our experimental kiln.

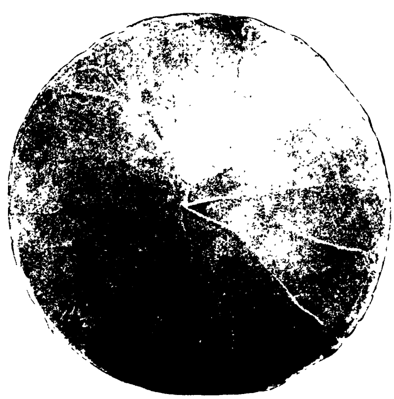

Fig. 3. Perfectly sound Portland cement made from available Philippine volcanic tuff.

PLATE I.

THE PHILIPPINE

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THE ABSORPTION SPECTRA OF VARIOUS PHTHALIDES AND RELATED COMPOUNDS, II

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Six text figures

The absorption spectra of phthalide and some of its derivatives both in alcohol and in concentrated sulphuric acid solutions were described in a previous paper.[1] It was shown that an intimate connection exists between the absorption bands given by these compounds and the character of substituting groups in the side ring or chain. When radicals are present that possess high residual affinities, the spectra deviate from the phthalic acid type to a greater or less extent, depending upon the degree of activity possessed by the substituting group. Two distinct phases are encountered in progressively increasing the activity of the nonbenzene portion of the molecule. The first tendency is to displace the absorption band and increase general absorption. This is followed by an actual splitting of the band into two or more bands, one of which, under ordinary circumstances, occurs in the region characteristic of simple disubstituted benzene derivatives. It was also shown that sulphuric acid with high residual affinity acting as a solvent for phthalides transferred energy to the side portion of the molecule with similar

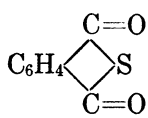
[1] Pratt, D. S., *This Journal, Sec. A* (1913), 8, 399.

results upon the spectra. The theory was advanced that such energy was supplied through the medium of conjugation between the solute and the sulphur atom of the acid, resulting, under certain favorable instances, in a conjugated ring characterized by selective absorption and the production of color. Several such cases were discussed, among which may be mentioned phthalophenone and its anilide. It was also pointed out that the substitution of thionyl for carbonyl in compounds of this type results in a very marked increase of activity. It has long been known that many such sulphur compounds are colored, generally a brilliant red, and this has been explained by attributing greater chromophoric power to thionyl than to carbonyl. Certain known compounds of this type and several new thio derivatives of phthalide have been prepared and their absorption spectra obtained.

DESCRIPTION OF THE ABSORPTION SPECTRA

The spectra were photographed in the usual manner, using an iron-nickel arc and Cramer's spectrum plates where necessary. The curves are plotted as in the previous paper. Absolute alcohol, glacial acetic acid, and concentrated sulphuric acid were used as solvents.

THIOPHTHALIC ANHYDRIDE



Thiophthalic anhydride was prepared from phthalic anhydride and sodium sulphide according to the excellent method of Reissert and Holle.[2] The product was repeatedly recrystallized from alcohol and obtained as colorless needles melting at 114° (corrected).

Analysis of thiophthalic anhydride.[3]

Substance.	Barium sulphate.	Sulphur.
Gram.	Gram.	Per cent.
0.2255	0.3355	20.44
Calculated for $C_8H_4O_2S$		19.54

[2] *Ber. d. deutsch. chem. Ges.* (1911), 44, 3029.

[3] Due to the rapid deterioration of hard glass in the tropics, Carius determinations are very difficult to carry out satisfactorily. This fact should be borne in mind in reference to the sulphur analyses here presented.

The glacial acetic acid solution was colorless, and gave a well-marked absorption band heading at $\frac{1}{\lambda} = 3340$ and showing considerable persistence. The anhydride in concentrated sulphuric acid gives a similar band heading nearer the red at $\frac{1}{\lambda} = 3130$ and appearing at somewhat lower concentration. Two new bands heading at $\frac{1}{\lambda} = 3860$ and $\frac{1}{\lambda} = 4200$ also show, the former being shallow and the latter well defined. General absorption more nearly approaches the visible region (fig. 1).

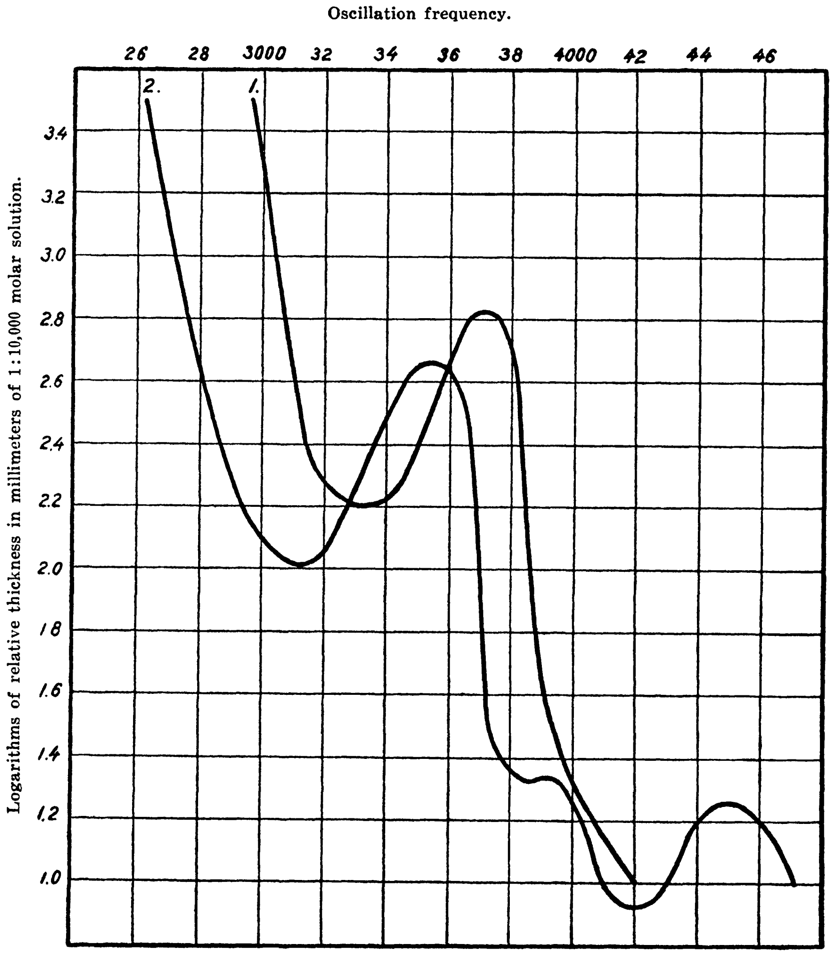
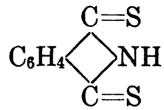


FIG. 1. *Curve 1.* Thiophthalic anhydride in glacial acetic acid. *Curve 2.* Thiophthalic anhydride in sulphuric acid.

DITHIOPHTHALIMIDE



This new and especially interesting sulphur derivative was prepared from phthalimide and phosphorous pentasulphide. Five grams of powdered sulphide were added to 5 grams of imide dissolved in 75 cubic centimeters of boiling xylol, and the heating was continued for about three hours. The solution rapidly turns red with the deposition of black and purple decomposition products. These are removed by decantation, and the solution is allowed to cool until the greater part of unchanged imide crystallizes out. This is also removed by decantation and the xylol distilled off in a current of steam. The residue was alternately recrystallized from benzol and alcohol, after boiling with bone black. The dithiophthalimide obtained in this manner formed brilliant red needles decomposing at 180° (corrected); yield, about 20 per cent. The compound decomposes readily, and is difficult to separate from traces of phthalimide.

Analyses of dithiophthalimide.

Substance.	Barium sulphate.	Sulphur.
Gram.	Gram.	Per cent.
0.1045	0.2475	32.54
0.0773	0.1986	35.30
Calculated	for $C_8H_5S_2N$	35.79

Substance.	Tenth-normal acid.	Nitrogen.
Gram.	cc.	Per cent.
0.2236	12.56	7.87
0.1515	8.76	8.10
Calculated	for $C_8H_5S_2N$	7.82

Dithiophthalimide in alcohol solution gave a complicated spectrum with a well-marked absorption band heading at $\frac{1}{\lambda} = 2020$ and appearing at high concentration. A rapid extension of general absorption was evident between $\frac{1}{\lambda} = 2400$ and $\frac{1}{\lambda} = 2700$ and two ultra-violet absorption bands heading at $\frac{1}{\lambda} = 3020$ and $\frac{1}{\lambda} = 3460$. Incipient benzene absorption at $\frac{1}{\lambda} = 3720$ was clearly indicated on the photographic plates, but the limits were

indefinite; hence the band was omitted in plotting the curve. The tenth molar concentration was deep red, becoming tinged with lavender upon dilution. The more concentrated solutions fluoresced slightly in the light of the arc.

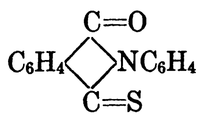
The salts of the alkali metals and ammonia are very soluble in water, and regenerate the imide upon the addition of acid. The absorption spectrum of the sodium salt was obtained with 90 per cent alcohol for the hundredth molar concentration. This solution is reddish yellow, becoming canary yellow on dilution with absolute alcohol for the lower concentrations. Higher concentrations of the salt are deep red in thick layers and yellow when viewed through thin films.

The spectrum showed a rapid extension in general absorption between $\frac{1}{\lambda} = 1900$ and $\frac{1}{\lambda} = 2300$ and a band at $\frac{1}{\lambda} = 2600$. The band at $\frac{1}{\lambda} = 3020$ was nearly obliterated, and that at $\frac{1}{\lambda} = 3460$ was considerably reduced in persistence.

Dithiophthalimide dissolves in concentrated sulphuric acid with a yellow color, giving an absorption spectrum with a well-marked band at $\frac{1}{\lambda} = 2780$ and the original band at $\frac{1}{\lambda} = 3460$.

Dithiophthalimide is readily soluble in pyridine with a red color, becoming orange upon decreasing the concentration. The absorption spectrum in freshly distilled pyridine, free from water, showed a small color band heading at $\frac{1}{\lambda} = 2020$ with high concentration, a rapid extension of transmission between $\frac{1}{\lambda} = 2400$ and $\frac{1}{\lambda} = 2700$, and an ultra-violet band at $\frac{1}{\lambda} = 2900$ (fig. 2, page 110).

THIOPHTHALANIL



Thiophthalanil was prepared from phthalanil and phosphorous pentasulphide.[4] After repeated boiling with bone black and recrystallization from glacial acetic acid and from alcohol, it was obtained in brilliant red needles melting at 145° (corrected), or 1° higher than found by Reissert and Holle.

The solution in glacial acetic acid was red, and with hun-

[4] Reissert und Holle, *loc. cit.*

dredth molar concentration produced an absorption band in the color region heading at $\frac{1}{\lambda} = 2070$. Two ultra-violet bands at $\frac{1}{\lambda} = 3060$ and $\frac{1}{\lambda} = 3480$ show with low concentration.

The absorption spectrum obtained with concentrated sulphuric acid as the solvent no longer contains the color band,

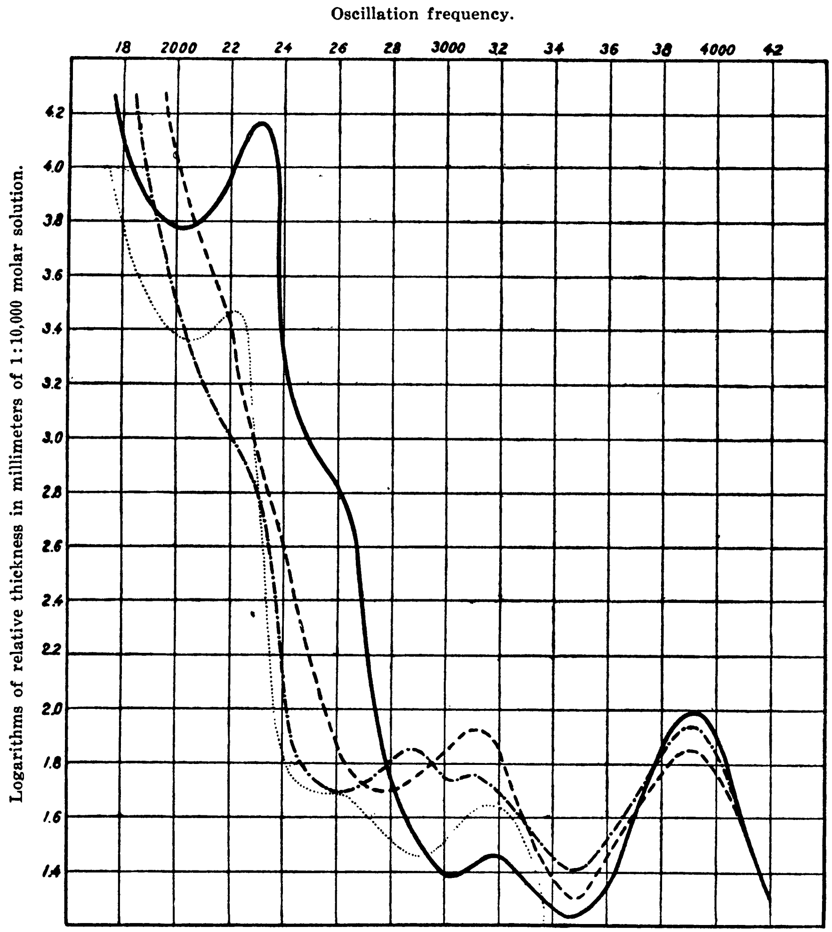
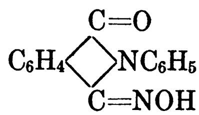


FIG. 2. *Full curve.* Dithiophthalimide in alcohol. *Dash-dot curve.* Dithiophthalimide in alcohol with 5 equivalentes of sodium ethoxide. *Dash curve.* Dithiophthalimide in sulphuric acid. *Dot curve.* Dithiophthalimide in pyridine.

but owes its reddish yellow color to general absorption. The ultra-violet bands are still present, heading at the same points as with acetic acid solvent, but the persistence of the one at $\frac{1}{\lambda} = 3060$ is greatly reduced (fig. 3).

PHTHALANIL OXIME



Phthalanil oxime was prepared from thiophthalanil and hydroxylamine.[5]

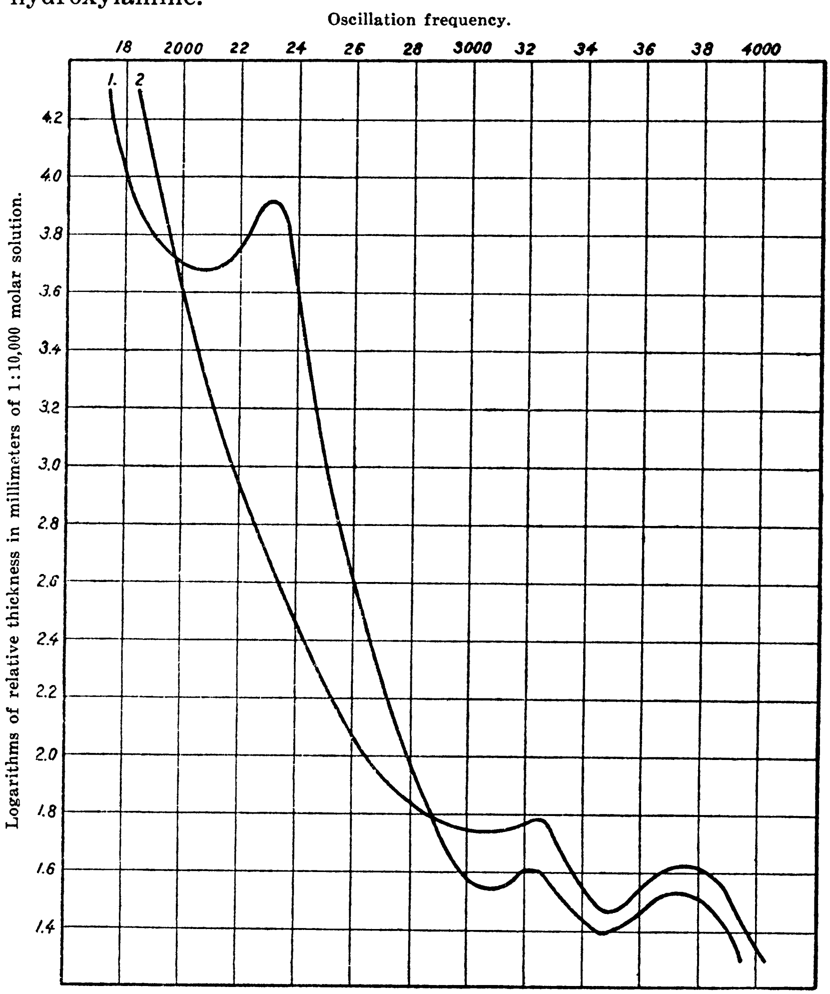


FIG. 3. *Curve 1.* Thiophthalanil in glacial acetic acid. *Curve 2.* Thiophthalanil in sulphuric acid.

Repeated recrystallization from methyl and from ethyl alcohol gave colorless needles melting with decomposition at 245°

[5] Reissert und Holle, *loc. cit.*

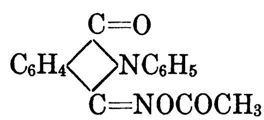
(corrected). The compound slowly becomes tinged with pinkish yellow on the surface upon standing in a desiccator over sulphuric acid. It agreed in all its properties with the description given by Reissert and Holle.

The alcohol solution fluoresced greenish in the light of the arc, and gave an absorption spectrum with a well-marked band heading at $\frac{1}{\lambda} = 3150$ and a more refrangible band in the benzene region at $\frac{1}{\lambda} = 3840$.

The addition of alkali turned the alcohol solution canary yellow and shifted the absorption band to $\frac{1}{\lambda} = 2900$, at the same time greatly reducing the persistence of selective absorption at $\frac{1}{\lambda} = 3840$.

Phthalanil oxime in concentrated sulphuric acid was also yellow, and gave a spectrum showing general absorption in the visible region with a rapid increase between $\frac{1}{\lambda} = 2500$ and $\frac{1}{\lambda} = 2700$. The remainder of the spectrum closely resembled that given by the alcohol solution (fig. 4).

PHTHALANIL OXIME ACETATE



This new derivative was prepared by dissolving phthalanil in an excess of acetic anhydride and allowing the solution to stand overnight. The acetate was precipitated by the addition of water and recrystallized from methyl alcohol in colorless needles melting without decomposition at 174° (corrected). It gradually turns yellow on standing in a desiccator over sulphuric acid.

Analysis of phthalanil oxime acetate.

Substance.	Tenth-normal acid.	Nitrogen.
Gram.	cc.	Per cent.
0.2000	14.27	10.00
0.2000	14.17	9.93
Calculated for $C_{16}H_{12}O_3N_2$		10.00

The absorption spectrum of an alcohol solution was very similar to that given by the oxime, but the persistence of the

band heading at $\frac{1}{\lambda} = 3150$ was slightly less. This solution in hundredth molar concentration fluoresced greenish in the light of the arc (fig. 4).

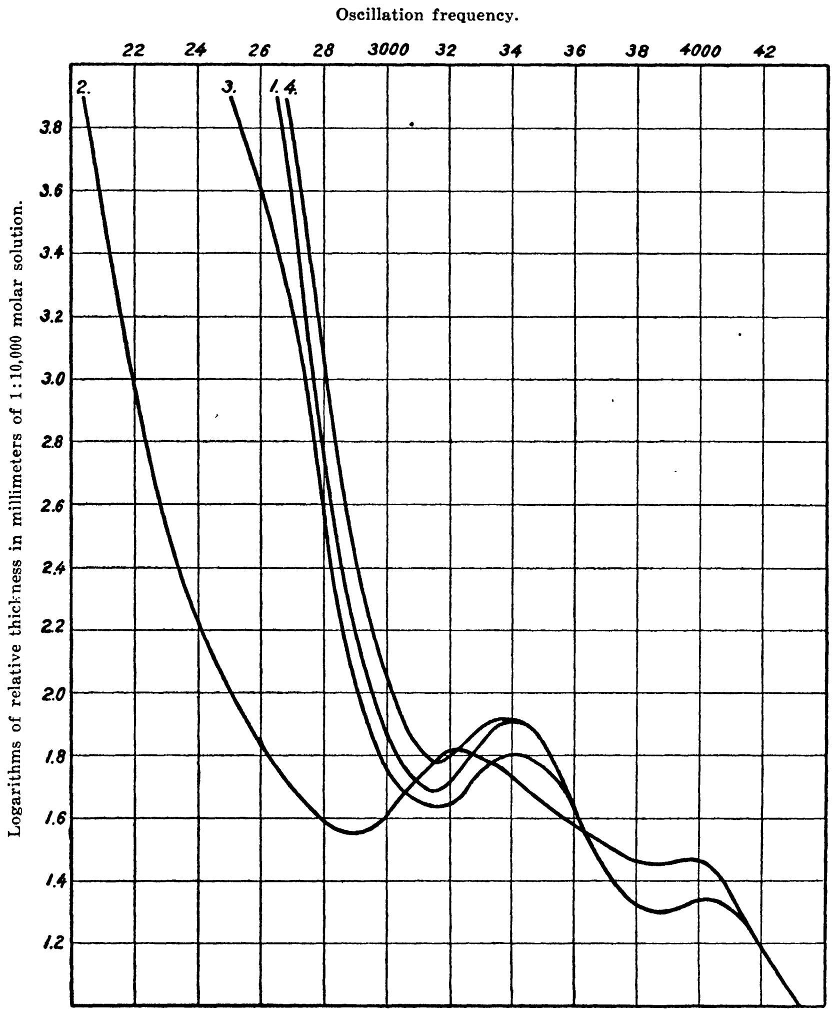
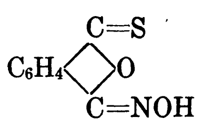


FIG. 4. *Curve 1.* Phthalanil oxime in alcohol. *Curve 2.* Phthalanil oxime in alcohol with 5 equivalents of sodium ethoxide. *Curve 3.* Phthalanil oxime in sulphuric acid. *Curve 4.* Phthalanil oxime acetate in alcohol.

THIOPHTHALOXIME



Thiophthaloxime was prepared by adding 10 grams of powdered phosphorous pentasulphide to 10 grams of phthaloxime dissolved in 250 cubic centimeters of boiling xylol. The solution upon continued boiling with a reflux condenser turns deep red and deposits purple- to black-colored decomposition products. After from two to three hours of gentle ebullition, the solution is cooled and decanted from unchanged oxime, sulphides, and decomposition products. The mother liquor deposits thiophthaloxime upon standing for some time in a cool place. The yield is meager, seldom exceeding 10 per cent and frequently even less. Larger amounts of original material give a lower percentage yield than when the reaction is carried out on a small scale.

The crude thio-oxime may be largely freed from phthaloxime by recrystallization from benzol in which it is much more soluble. Recrystallized from benzol and from alcohol, thiophthaloxime forms long red needles melting with decomposition at 148°.5 (corrected). The compound loses sulphur easily, and is difficult to obtain pure.

Analyses of thiophthaloxime.

Substance.	Tenth-normal acid.	Nitrogen.
Gram.	cc.	Per cent.
0.2015	11.12	7.73
0.3010	16.52	7.69
Calculated for $C_8H_5O_2NS$		7.78

Substance.	Barium sulphate.	Sulphur.
Gram.	Gram.	Per cent.
0.2125	0.2455	16.23
Calculated for $C_8H_5O_2NS$		17.81

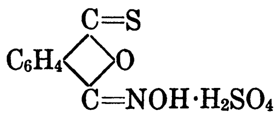
An alcohol solution gave an absorption spectrum with a clearly indicated, although shallow, color band heading at $\frac{1}{\lambda}=2040$; a small band at $\frac{1}{\lambda}=3040$, and a well-marked band at $\frac{1}{\lambda}=3480$.

The addition of alkali turned the alcohol solution a purplish red, and the spectrum of such a solution containing 1 equivalent of sodium ethoxide showed a very broad and deep color band heading at the same point as before; that is, $\frac{1}{\lambda}=2040$, but appearing in thousandth molar concentration.

The band at $\frac{1}{\lambda} = 3040$ was reduced to a mere fraction of its original size, and that at $\frac{1}{\lambda} = 3480$ was nearly destroyed.

Thiophthaloxime dissolves in concentrated sulphuric acid solution with a yellow color. The absorption spectrum of such a solution showed no band in the visible region. The color is, therefore, due to general absorption. The small band in the ultra-violet was shifted to $\frac{1}{\lambda} = 2880$, and the persistence of the band heading at $\frac{1}{\lambda} = 3480$ was reduced.

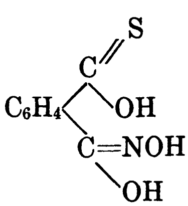
THIOPHTHALOXIME SULPHATE



Thiophthaloxime dissolves in concentrated sulphuric acid to form a sulphate that may be obtained by pouring the solution into an excess of ice water. The sulphate slowly crystallizes out in long yellow needles on standing. Recrystallized from dry benzol, it was obtained in stout yellow prisms melting with slight decomposition at 159° (corrected).

The sulphate is soluble in absolute alcohol with a yellow color. Upon the addition of water and boiling, the solution turns red, showing the splitting off of sulphuric acid and regeneration of thiophthaloxime. The solution in absolute alcohol gave an absorption spectrum with bands at $\frac{1}{\lambda} = 3100$ and $\frac{1}{\lambda} = 3700$. General transmission extends into the ultra-violet a much greater extent than with the free oxime (fig. 5, page 116).

The metallic salts of thiophthaloxime are highly colored, those of ammonia and the alkali metals being purple. They are very unstable in the presence of moisture, and rapidly go over into colorless salts of thiophthalhydroxamic acid.



An aqueous solution of the sodium salt became colorless almost immediately, and gave a reddish purple color with ferric chloride, showing the presence in the colorless solution of hydroxamic acid. The sodium salt may be obtained by adding

the required amount of sodium ethoxide to thiophthaloxime dissolved in absolute alcohol and evaporating to dryness in vacuo over sulphuric acid. The salt is deep purple in color, and possesses a very disagreeable, garliclike odor, probably due to gradual decomposition.

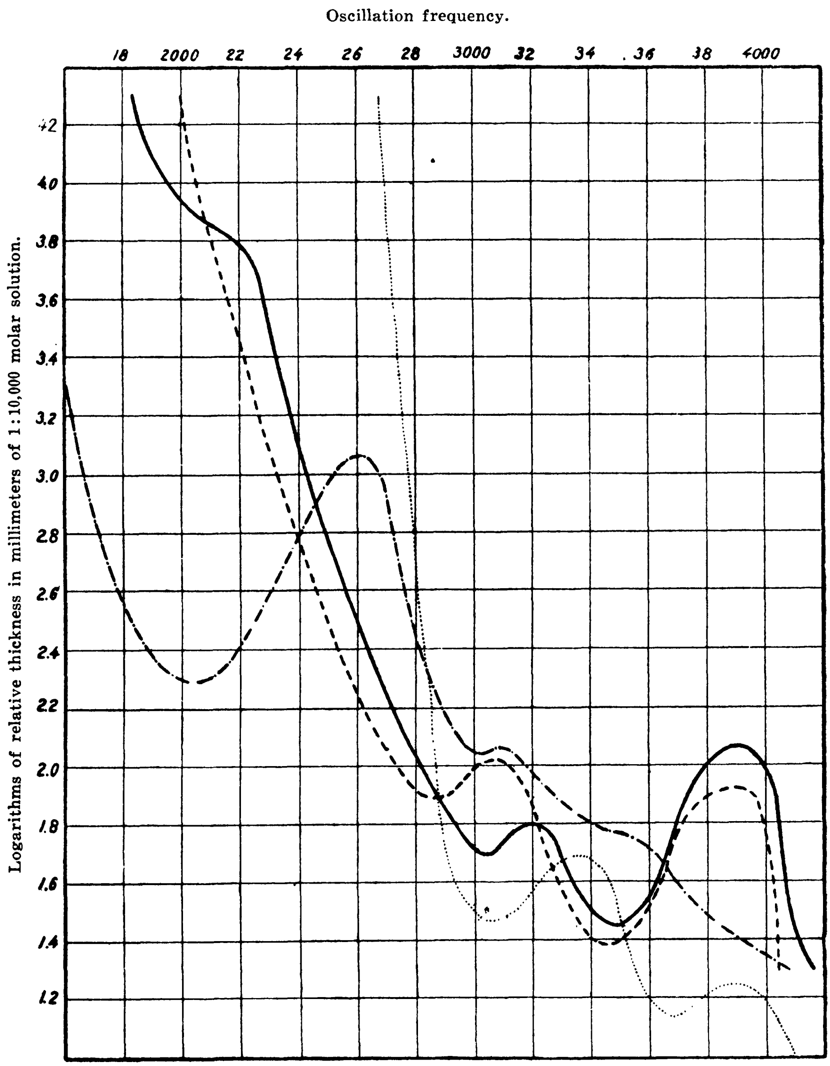


FIG. 5. *Full curve.* Thiophthaloxime in alcohol. *Dash-dot curve.* Thiophthaloxime in alcohol with 1 equivalent of sodium ethoxide. *Dash curve.* Thiophthaloxime in sulphuric acid. *Dot curve.* Thiophthaloxime sulphate in alcohol.

The ammonia salt was prepared by passing dry ammonia gas over a weighed amount of thiophthaloxime placed in a

porcelain boat. The red oxime rapidly turned purple, and gained in weight corresponding to the addition of one molecule of NH_3.

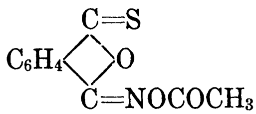
Formation of ammonium salt of thiophthaloxime.

Sample.	Gain.	Gain.
Gram.	Gram.	Per cent.
0.3195	0.0285	8.92
Calculated for $C_8H_4O_2NS{\cdot}NH_4$		8.68

The salt did not lose ammonia when exposed to a current of carefully dried air, but rapidly became colorless in the presence of moisture.

The silver salt forms at once as a purple precipitate when a solution of silver nitrate is added to the oxime dissolved in absolute alcohol or to an aqueous solution of the ammonium salt. In both cases, the salt undergoes decomposition almost immediately with the formation of silver sulphide. No analysis, therefore, of the silver salt was attempted.

THIOPHTHALOXIME ACETATE



Thiophthaloxime acetate was made by allowing the oxime to stand overnight at room temperature in the presence of an excess of acetic anhydride. The oxime slowly goes into solution under these conditions, and the acetate may then be precipitated in nearly quantitative yield by the addition of water. It is very soluble in acetic acid and in ethyl alcohol, from which it crystallizes in orange plates melting without decomposition at 104° (corrected).

Analyses of thiophthaloxime acetate.

Substance.	Tenth-normal acid.	Nitrogen.
Gram.	cc.	Per cent.
0.2078	9.41	6.35
0.2109	9.52	6.32
Calculated for $C_{10}H_7O_3NS$		6.34

Substance.	Barium sulphate.	Sulphur.
Gram.	Gram.	Per cent.
0.2370	0.2340	13.57
Calculated for $C_{10}H_7O_3NS$		14.52

Thiophthaloxime acetate in alcohol gave an absorption spectrum differing from that of thiophthaloxime only in the extent

of general absorption, the absence of a color band at $\frac{1}{\lambda} = 2040$, and reduced persistence of the band at $\frac{1}{\lambda} = 3480$. The ultra-violet bands are otherwise the same in the two compounds (fig. 6).

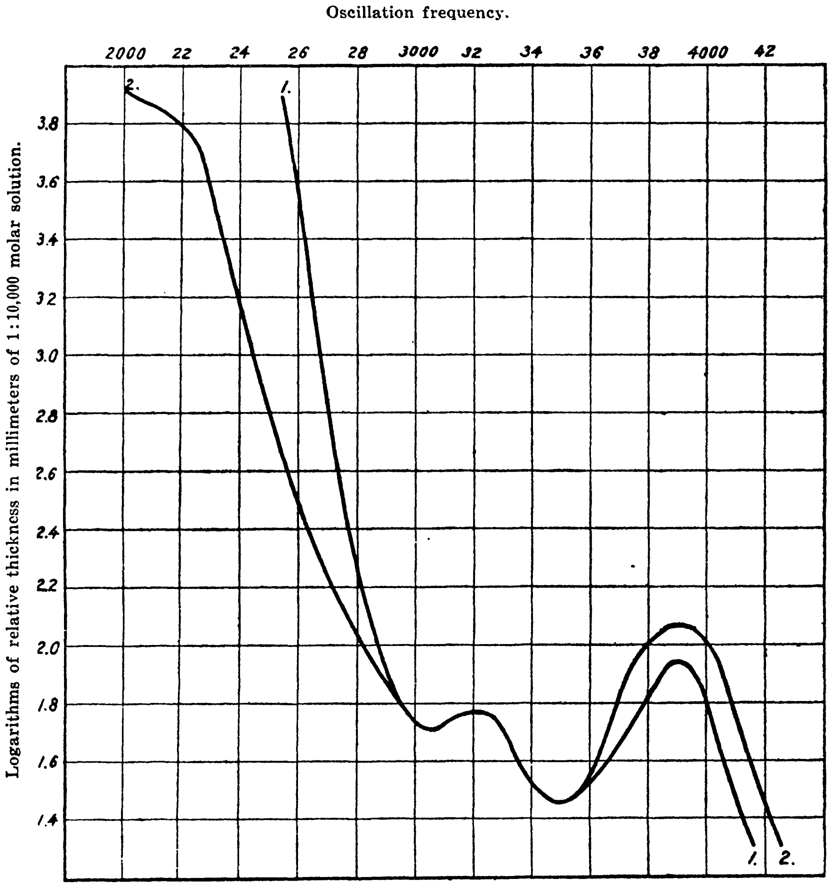


FIG. 6. *Curve 1.* Thiophthaloxime acetate in alcohol. *Curve 2.* Thiophthaloxime in alcohol.

DISCUSSION OF RESULTS

The substitution of sulphur for oxygen in phthalic anhydride causes a marked change in the absorption spectrum. The band given by a glacial acetic acid solution is shifted from $\frac{1}{\lambda} = 3440$ to $\frac{1}{\lambda} = 3340$, and is increased threefold in persistence while still retaining the phthalic anhydride type. General absorption

much more nearly approaches the visible region, and the spectrum clearly indicates increased activity of the lactone ring. The spectrum of the sulphuric acid solution is particularly significant. The single band of the acetic acid solution has been separated into 3 bands, one nearer the red and two in the far ultra-violet. The shift of the band from $\frac{1}{\lambda} = 3340$ to $\frac{1}{\lambda} = 3130$ is slightly greater than in the case of phthalic anhydride under similar conditions, and is entirely analogous, although the increase of persistence and the difference in concentration at which it appears are both decidedly less marked.

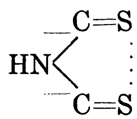
The more refrangible band given by phthalic anhydride in sulphuric acid solution is represented by two smaller bands in its thio-derivative. The small band heading at $\frac{1}{\lambda} = 3860$ closely approximates the position of that given by phthalic anhydride in this solvent at $\frac{1}{\lambda} = 3800$, but the latter is of considerable width and depth while the former is small and very shallow. The band at $\frac{1}{\lambda} = 4200$ has no counterpart in the spectrum of phthalic anhydride. It is probable that the band of this compound represents a combination of the two bands in near-by regions given by thiophthalic anhydride and that the substitution of sulphur for oxygen results in a sufficient increase of activity to permit their separation by sulphuric acid. This does not conflict with the theory advanced to explain the action of sulphuric acid on compounds of this type. The two carbonyl groups are still present in the thio-anhydride, and one would expect greater activity of the lactone ring in ordinary solvents and corresponding changes in sulphuric acid.

We have not been successful in various attempts to replace carbonyl by thionyl, using methods similar to those employed for thiophthaloxime or dithiophthalimide. Richard Meyer [6] states that he obtained similar negative results when the anhydride was fused with phosphorous pentasulphide. The chemical behavior and absorption spectrum of thiophthalic anhydride leave no doubt but that the sulphur atom replaces the anhydride oxygen, giving a symmetrical molecule. Since thiophthalic anhydride reacts readily with hydroxylamine elim-

[6] *Ber. d. deutsch. chem. Ges.* (1900), **33**, 2574.

inating hydrogen sulphide, it was hoped that further proof concerning the structure of phthaloxime [7] might thus be obtained. Unfortunately, it was not possible to replace directly the sulphur atom by the oximido group with the formation of a symmetrical oxime. The reaction always took place with the intermediate formation of phthalhydroxamic acid and opening of the lactone ring. This question will be discussed again under thiophthaloxime.

A comparison between the absorption spectra of dithiophthalimide and phthalimide [8] shows points of relationship as well as characteristic differences. The band heading at $\frac{1}{\lambda}=3460$ is common to both, but is more pronounced in the former compound. Incipient benzene bands are evident in the spectra, but phthalimide produces no bands corresponding to those heading at $\frac{1}{\lambda}=2020$ and $\frac{1}{\lambda}=3020$. The addition of alkali shifts general absorption toward the red in both cases, but with the sulphur derivative more complicated changes accompany salt formation. The elimination of the color band and appearance of a new band at $\frac{1}{\lambda}=2600$ can be satisfactorily explained by considering the relationships existing between partial valencies before and after salt formation. The color band heading at $\frac{1}{\lambda}=2020$ probably owes its origin to conjugated linking between the two thionyl groups, as represented by the formula:



The introduction of metal in place of imido hydrogen tends to attract the partial valency of sulphur, thus diminishing this conjugation and reducing the color band of the imide to a rapid extension of general absorption as given by solutions of its salt. This shifting of valency must produce a new equilibrium, and in fact a new absorption band appears in the spectrum heading at $\frac{1}{\lambda}=2400$ while the band at $\frac{1}{\lambda}=3020$ nearly disappears.

[7] Orndorff and Pratt, *Am. Chem. Journ.* (1912), **47**, 89; Pratt and Gibbs, *This Journal, Sec. A* (1913), **8**, 165.

[8] Pratt, *This Journal, Sec. A* (1913), **8**, 405.

Phthalimide itself shows a tendency toward similar changes as evidenced by the marked widening of its absorption band upon salt formation. The attraction between oxygen and metal must be considerably less than that between sulphur and metal; consequently, the compound with two carbonyl groups undergoes less rearrangement of its partial valencies upon the introduction of a metal atom into the molecule.

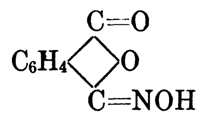
The changes characteristic of salt formation in the case of dithiophthalimide are thus diametrically opposite to corresponding changes with phthaloxime. The former compound is red with a band in the visible spectrum, while its alkali salts are reddish yellow and produce no color band. The latter is colorless, and gives no selective absorption in the color region, while its salts are red and show a strong color band. This is the most striking example thus far encountered in confirmation of the theory explaining color formation as dependent upon shifting of partial valency equilibrium when phthaloxime is converted into its salts. It also contributes valid evidence in favor of the unsymmetrical structure of phthaloxime, since dithiophthalimide is undoubtedly symmetrical and would necessarily show an analogous absorption spectrum if it possessed a structure similar to that of the oxime.

The spectrum given by pyridine solutions of dithiophthalimide is also of special interest. It contains a well-marked color band similar to that given by alcohol solutions but appearing at less concentration, and the band characteristic of alkali salts heading at $\frac{1}{\lambda} = 2600$ is represented by a step-off (fig. 2). The results of pyridine on dithiophthalimide are thus the reverse of those characteristic for phthaloxime in this solvent.[9] The latter compound in pyridine solution gives no color band, because this base is not sufficiently active to cause the partial valency equilibrium necessary for its genesis. In the case of dithiophthalimide, also in pyridine solution, the color band does not disappear from the spectrum as in the alkali salts, because again the base does not possess enough residual affinity to upset the conjugation already taking place between the two thionyl groups. This reversal of the effects caused by pyridine is what might be anticipated if the correctness of our views regarding partial valency equilibrium be granted, but is otherwise difficult to explain.

The presence of thionyl replacing carbonyl cannot be responsible for the reversal of the effect produced by alkali. Thio-

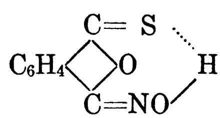
[9] Pratt and Gibbs, *loc. cit.*

phthaloxime is red, and its absorption spectrum shows a shallow color band at $\frac{1}{\lambda} = 2040$. The alkali salts are purple, and give very strong selective absorption with a broad, deep band heading at the same wave length. The effect of alkali, therefore, is identical with thiophthaloxime and phthaloxime. The presence of thionyl does not reverse the spectroscopic changes due to salt formation. Furthermore, two thionyl groups are readily introduced into phthalimide, while only one could be introduced into phthaloxime. Thus chemical and spectroscopic evidence



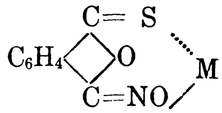
is in complete accord with the structural formula for phthaloxime, and we consider that this may now be accepted as correct.

Thiophthaloxime in alcohol gives a deep red solution and an absorption spectrum with a band in the color region. The addition of alkali greatly increases the width and persistence of this band, and at the same time nearly obliterates selective absorption in the ultra-violet. It is evident that an ascending scale may be arranged, corresponding to increasing activity of the side ring with phthaloxime, thiophthaloxime, salts of phthaloxime, and salts of thiophthaloxime. The first member of the series causes no selective absorption in the visible region of the spectrum, and corresponds to the structural formula given above. The substitution of thionyl for carbonyl results in a considerable increase of activity, so much so that thiophthaloxime, although possessing the same molecular arrangement as phthaloxime, nevertheless is a brilliant red and causes a color band in solutions of hundredth molar concentration. We consider this due to conjugation between thionyl and oximido groups, as represented by the formula:



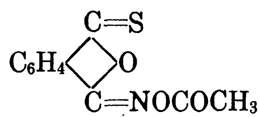
The equilibrium in this direction is considerably less important than in the case of salts of phthaloxime as the tendency for conjugation between thionyl sulphur and hydrogen is less than between carbonyl oxygen and metal.

In a like manner, the introduction of a metal atom in thiophthaloxime gives a maximum reciprocal effect, represented by the formula:



The heavy dots between sulphur and metal may serve to indicate that the equilibrium of partial valency is emphasized in the salt, while the corresponding light dots show the lesser importance of conjugation in the oxime.

The color and selective absorption of thiophthaloxime cannot be explained by molecular rearrangement. The compound still contains a hydroxyl group capable of giving an acetate with acetic anhydride. The acetate is orange, but gives an absorption spectrum containing no color band. Its color is due entirely to general absorption, and the reason that this cuts into the visible region while that of phthaloxime acetate is much farther toward the shorter wave lengths at corresponding concentrations is to be attributed to the greater activity of the lactone ring containing sulphur. The structure of the acetate, therefore, is correctly represented by the formula:



The molecular arrangement of the acetate must be identical with that of the oxime as the ultra-violet bands of both substances are identical (fig. 6).

All of these relationships taken together conclusively show that the spatial arrangement of the molecules of phthaloxime, its salts, ethers, and esters, and of the corresponding thiophthaloxime compounds is the same in each case. No rearrangement of the molecule takes place upon salt formation, and the production or variation of color must be dependent upon changes in conjugation between partial valencies.

Thiophthaloxime dissolved in concentrated sulphuric acid gave a much simpler absorption spectrum (fig. 5). Since the sulphate was isolated from this solution, the spectrum doubtless represents the combination of oxime and acid. Such an addition product must not be confused with the type of conjugated combination postulated for such a substance as phthalophenone in

sulphuric acid, which exists only in solution and is at once broken up by dilution with water, while thiophthaloxime in sulphuric acid represents true chemical combination and corresponds to similar addition products, such as benzaldoxime hydrochloride, phenolphthalein oxime hydrochloride, etc.

The absorption spectrum of thiophthaloxime sulphate in alcohol is very different from that given by the oxime in concentrated sulphuric acid (dot curve, fig. 5). The general transmission of the former extends much farther into the ultraviolet, and the two bands are more refrangible. The spectrum is distinctly approaching the phthalide type, and shows the decreased activity of the side ring caused by satisfying the two extra normal valencies of the nitrogen atom.

The spectrum given by phthalanil oxime shows the decreased activity of the lactone ring when anhydride oxygen is replaced by the aniline residue. The reduction is entirely analogous to that noted in comparing the spectra of phthalophenone and phthalophenone anilide in alcohol as well as in sulphuric acid solutions.

The action of alkali on phthalanil oxime in alcohol is to shift the band nearer the red, reduce the more refrangible band, and extend general absorption into the visible region with the production of a yellow color. Concentrated sulphuric acid has only a slight effect, and the change to acetate has even less.

The absorption spectra of various other closely related compounds will be presented in a future paper.

SUMMARY

1. The absorption spectra of various phthalides containing sulphur replacing oxygen have been studied in ordinary solvents and in concentrated sulphuric acid.

2. Dithiophthalimide and thiophthaloxime have been prepared, and satisfactory proof has been obtained from their spectra in support of the unsymmetrical structure for phthaloxime.

3. Further evidence has been presented that color production upon salt formation in oximes of this type is not due to molecular rearrangement, but is dependent upon changes in partial valency equilibrium.

4. The theory regarding color in thionyl derivatives of phthalides has been extended.

ILLUSTRATIONS

TEXT FIGURES

THE EFFICIENCY OF PORTLAND CEMENT RAW MATERIALS FROM NAGA, CEBU

By W. C. Reibling and F. D. Reyes

(From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.)

Two plates

INTRODUCTION

In the interest of certain prospective manufacturers, the most promising of the raw materials from Naga, Cebu, were collected by Mr. Wallace E. Pratt, a geologist of the Bureau of Science, and submitted to as comprehensive an investigation as was necessary definitely to establish the relative merits and suitability for the commercial manufacture of Portland cement. Before presenting our experimental work, we shall discuss a few considerations which appear to be generally misunderstood or overlooked.

Most of the materials had already been tested by two laboratories in the United States, and they reported results which, with a few exceptions, were satisfactory. However, the few unsatisfactory features involved considerations of such vital importance that the prospective manufacturers could not accept the data obtained as sufficient evidence to justify further steps toward the establishment of a plant. Finally, they submitted the reports to the Bureau of Science, and requested our interpretation of their significance.

The laboratories in question did the work which they were requested and paid to do in a very honest and painstaking manner, and while we criticize certain of their methods and conclusions this is not done in an attempt to cast reflections on their work and reputation. Their methods compare favorably with those of most laboratories, and their conclusions are based upon generally accepted theories and practices, some of which are of doubtful value. We shall make specific reference to their reports, because their data stand as official records against many of our own conclusions on the merits of these raw materials.

We fail to find much significance or usefulness in results

obtained, as in this instance, by submitting each combination of different raw materials to only one burning test. A burning test may produce excellent cement, but the results obtained might be so seriously affected by unavoidable variations in factory conditions as to exclude the possibility of their successful commercial use. On the other hand, a burning test may give very unsatisfactory results, and yet a thorough study of the raw materials used may reveal commercially practicable conditions of manufacture which will produce extremely good results.

Slight variations in composition, degree of burning, and pulverization are unavoidable both in laboratory and manufacturing practices, and such changes modify the quality of the product more or less according to the nature of the raw materials. Therefore, it is necessary to ascertain the effects produced by reasonable modifications in the hydraulic index, degree of vitrification, fineness, etc. This is especially true if, as in this instance, we desire to know the relative merits of available raw materials and the conditions of manufacture which will produce the best results from the standpoint of manufacturing efficiency. The changes brought about by well-planned modifications in the conditions of manufacture will be the more significant the more closely the experimental conditions approach those of the best commercial practices. This is especially true with respect to the degree of vitrification.

A very objectionable feature of many reports is that the results were obtained with underburned or unsound cement. Such products have no definite characteristics in setting or hardening properties. They may develop considerable strength in seven or twenty-eight days only to disintegrate entirely after a few months, and both their set and strength may change from a satisfactory to an unsatisfactory one, or vice versa, overnight. In reality they are not true Portland cements but a mixture of lime; hydraulic limes; and Roman, slag, and Portland cements. Obviously, it is misleading to judge the efficiency of raw materials from results obtained by improper burning. It is much more logical to ascertain the possibilities of well-sintered mixtures, to observe whether good burning would be practicable under commercial conditions, and then to take into consideration such allowance as must be made for unavoidable variations and imperfections in commercial manufacture.

If the clinker is allowed to cool slowly with the experimental kiln, the results obtained may be characteristic only of the set-

kiln products. In the rotary kiln process the clinker is cooled much more rapidly, and if, as in this instance, the prospective manufacturers intend to install rotaries the clinker from the experimental burnings should be cooled accordingly. It was for this reason that we designed a furnace which enables us to dump the clinker and cool it as rapidly or as slowly as desired.

The necessity of testing the resulting cements in a thorough and comprehensive manner is also imperative. This is especially true of the "time of setting." The extent and manner in which the setting properties of cements may change owing to the influence of slight variations in the quantity of retarder or degree of seasoning, the means whereby it is possible to ascertain if the set is capable of being kept within desirable limits during storage, and the minimum amount of retarder required have been fully described.[1] Yet, it is the common practice of many laboratories to add 2 or 2.5 per cent of plaster to the cement and submit the result obtained as characterizing its setting properties. Nothing is apt to be more misleading, as the following incident will serve to show.

One of the reports submitted to our inspection showed that the tester had added 2 per cent of calcined gypsum and obtained a cement which required an excessively high percentage of water for normal consistency and gained its initial and final sets in about five and one-half and nine hours, respectively. These and other similar results made it appear that the manufacturers would have considerable difficulty in producing Portland cement from these raw materials which would set and harden with sufficient rapidity.

However, for reasons which we have already thoroughly discussed,[2] the opinion was expressed that these cements really set so quickly that they became partially regauged and consequently abnormally slow setting during the mixing process. The commonness of errors of this kind has been pointed out. In fact, so far as our experience goes, the regauging of extremely quick-setting cements is the main cause of the serious discrepancies which occasionally occur between the reports of the set from the manufacturer and those of the consumer. Nine-tenths of the cements which, when tested in the cement laboratory of the Bureau of Science, failed to pass our standard specifications did so only because they set with abnormal quickness. Fully

[1] *This Journal, Sec. A* (1912), **7**, 207–252.
[2] *Ibid.* (1911), **6**, 248.

one-half of these could not have produced a slow-setting paste before they were packed, unless regauging had taken place to a considerable extent during the process of mixing.

We also disputed the correctness of the assumption that the cements obtained from these raw materials would set and harden slowly, because the value of the ratio of silica to alumina was high. Apparently many experts believe that the early hardening properties of Portland cement are due to the aluminates. If this were true, we could not account for the rapid development of great strength and quick-setting properties of many well-burned, highly siliceous Portland cements which have come under observation. Our own extensive researches verify the work of Dr. O. Schott [3] that the quick-hardening compounds of Portland cement are formed at a high temperature and that with the silicates the strength increases as the lime increases while with the aluminates the opposite is true; and as the high silicates and the low aluminates require the greatest heat it is evident that high temperatures produce high strength.

We further expressed the opinion that a high silica cement should carry more calcareous material than one with less silica and more alumina and that in several instances the hydraulic moduli of mixtures prepared in the United States were too low. We realized that an increase in the calcareous constituents would raise the clinkering temperature, but believed that there was sufficient iron oxide in the raw materials to permit higher liming. For the same reasons, the use of less siliceous materials did not seem desirable, much less, necessary.

While many of the problems involved in the successful and economic manufacture of Portland cement cannot be solved by laboratory experiments, we believe that an investigation such as is outlined and described in the following pages will establish the relative merits of different raw materials and point out the most important of the conditions of manufacture which will produce the most desirable results.

EXPERIMENTAL WORK

The geology, field relations, and physical characteristics of the raw materials are discussed by Mr. Pratt on pages 151 to 161. The chemical characteristics of each of the 8 samples of raw materials examined are made apparently by the data in Table I.

[3] *Cement & Eng. News* (1910), 22, Nos. 9–13.

TABLE I.—*Ultimate chemical composition of the raw materials.*

Constituent.	Sample No.								
	35.	37.	39.	46.	47.	48.	49.	50.	51.
Loss by ignition	35.90	36.70	38.92	41.90	8.50	8.07	8.44	40.55	19.45
Total silica (SiO_2)	14.87	8.94	8.25	3.80	70.28	60.29	58.59	3.20	41.97
Alumina (Al_2O_3)	2.18	0.43	2.37	2.18	11.89	15.04	18.53	0.35	8.66
Ferric oxide (Fe_2O_3)	2.20	3.09	0.61		2.36	12.05	7.58	1.39	9.54
Calcium oxide (CaO)	43.12	47.40	46.52	51.59	2.55	1.37	2.69	53.16	15.12
Magnesia (MgO)	0.87	0.82	0.82	1.44	0.91	2.29	2.25	0.59	2.16
Sulphur oxide (SO_3)	trace	trace	trace	none	trace	trace	0.11	0.10	0.32
Free silica	2.82	3.51	none	trace	9.34	8.24	5.12	1.76	2.12
Total alkalies (Na_2O, K_2O)	0.84	0.66	0.62	0.46	3.73	1.18	2.10	0.36	2.31

It was thought advisable to combine samples 35, 37, and 39 into one mixture composed of equal parts of each. Mr. Pratt states that such a mixture represents the probable average output of the most feasible quarry site, although if desirable it would be almost as convenient to confine operations to the beds represented by 37 and 39.

The first mixtures prepared for burning were combined so that the hydraulic modulus

$$\left(\frac{\text{per cent CaO}+\text{per cent MgO}}{\text{per cent SiO}_2+\text{per cent R}_2\text{O}_3}\right)$$

of each of the resulting cements would approximate 2. The calcareous material represented by the mixture of 35, 37, and 39 was given the most consideration, because these limestones are said to be the most conveniently located and most easily quarried of the available calcareous supplies. The essential characteristics of the four mixtures prepared for the first burning tests are given in Table II.

TABLE II.—*Characteristics of the first four cement mixtures.*

Mixture No.	Material.	Parts by weight.	Fineness through the 100-mesh sieve.
			Per cent.
1	Limestone 50	100	92
	Clay 48	27	
2	Limestones 35, 37, and 39	100	95
	Clay 47	9	
3	Limestones 35, 37, and 39	100	94
	Clay 51	18	
4	Limestones 35, 37, and 39	100	93
	Clay 49	10	

TABLE II.—*Characteristics of the first four cement mixtures*—Continued.

PRINCIPAL ULTIMATE CONSTITUENTS AFTER VITRIFICATION (BY CALCULATION).

Constituent.	Mixture No.			
	1.	2.	3.	4.
Silica (SiO_2)	23.10	23.90	23.55	23.00
Alumina (Al_2O_3)	5.22	3.14	4.15	4.87
Ferric oxide (Fe_2O_3)	5.50	3.05	4.34	3.76
Calcium oxide (CaO)	63.60	64.70	62.50	63.70
Magnesia (MgO)	1.43	1.28	1.57	1.46
Hydraulic modulus $\left(\frac{\%CaO+\%MgO}{\%SiO_2+\%R_2O_3}\right)$	1.92	2.15	1.97	2.10

REFRACTORY PROPERTIES.

Mixture No.	Observations.
1	Easily sintered into well-burned clinker at a temperature considerably below the melting point, and no tendency of product to dust.
2	Similar to 1, but a little more refractory.
3	Similar to 1, but if fused the clinker dusted completely while cooling.
4	Ideal refractory properties, and no tendency to dust when cooling.

Throughout this work the various materials and products were not ground to a greater degree of fineness than is customary in commercial manufacture, although in most instances better results could have been obtained by so doing.

After the addition of sufficient water, each mixture was molded into briquettes and burned practically without contamination to the point of incipient fusion, the accepted product being analogous to well-burned rotary clinker. The clinkers were crushed in a jaw crusher, mixed with 1 per cent plaster, and ground by means of a tube mill employing manganese-iron balls, to the degree of fineness demanded by our cement specifications. The finished products were then subjected to preliminary tests for soundness.

As shown by the attached photographs in Plate I, all of the steamed pats remained perfectly sound. They all adhered firmly to the glass plates, and showed excellent color and texture. As the cements had not been seasoned, their soundness proved conclusively that the clinker had been well burned. Furthermore, observations during the process of burning showed that the mixtures would meet the requirements of commercial kilns.

The briquettes vitrified at a comparatively low temperature, slightly lower than the raw meal used for the manufacture of "Green Island" Portland cement, but sustained such a considerable increase in temperature without fusing that no difficulty was experienced in producing good, thoroughly sintered clinker without melting part of the charge. There also was practically no "dusting" when the well-sintered, uncontaminated clinker cooled.

We were prepared to make a thorough study of the setting properties of these cements under different conditions of seasoning, grinding, and plastering, but a few tests showed that there need be no difficulty in controlling their setting properties and that the amount of plaster or gypsum required could be maintained at a low figure.

The results obtained with the nonseasoned cement are recorded in Table III.

TABLE III.—*Essential characteristics of the nonseasoned cements produced from the first four mixtures.*

Test.	Mixture No.			
	1.	2.	3.	4.
Fineness:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Through the 100-mesh sieve	98.8	97.8	98.2	97.8
Through the 200-mesh sieve	79.4	77.6	77.8	77.6
Soundness, 5-hour steam test	sound	sound	sound	sound

Setting properties.

Mixture No.	Plaster added.	Water required for normal consistency.	Initial set.	Final set.
	Per cent.	*Per cent.*	*Hrs. min.*	*Hrs .min.*
1	1	21	3 00	5 55
2	1	22	1 10	6 10
3	1	[a]27	Flash set.[a]	
4	1	21	35	5 25
1	2	20.5	2 30	5 00
2	2	21	3 50	5 50
3	2	21	1 30	5 30
4	2	20	3 00	5 00

[a] The set was almost instantaneous, but when the cement was manipulated according to specification an extremely slow-setting paste resulted which, in reality, was a regauged cement. [Cf. *This Journal, Sec. A* (1911), **6**, 207–252.]

All commercial cements season more or less during the process of manufacture. The cements under consideration required no seasoning, but it was thought advisable to aërate[4] them in the laboratory for twenty-one hours spread out in layers about 2.5 centimeters in thickness, after which they were subjected to all specified tests. The results obtained, together with the requirements of the standard specifications now in operation, are given in Table IV.

TABLE IV.—*Physical properties of the Portland cements obtained from the first four mixtures.*[a]

Test.	No. 1.	No. 2.	No. 3.	No. 4.	Specified requirements.
Fineness:					
Per cent through the 100-mesh sieve	98.9	98	98.4	98.2	92
Per cent through the 200-mesh sieve	78	78.6	78.8	78.4	75
Specific gravity (dried at 110° C.)	3.16	3.15	3.16	3.16	3.1
Water required for normal consistency	20	21	20	20	none
Soundness, air, water, and steam	sound	sound	sound	sound	sound
Time of setting in hours:					
Initial set	2.8	3.3	0.9	3.2	(b)
Final set	5.5	4.8	2	4.6	(c)
Tensile strength in pounds per square inch:					
1-day, neat mortar	507	404	370	420	none
7-day, neat mortar	860	740	520	755	500
28-day, neat mortar	840	780	605	780	600
7-day, 1:3, Ottawa-sand mortar	315	298	258	275	200
28-day, 1:3, Ottawa-sand mortar	410	360	320	360	275
PRINCIPAL CONSTITUENTS OF THE NONPLASTERED CEMENTS (BY ANALYSES).					
Silica (SiO_2)	22.65	23.95	23.80	23.10	
Alumina (Al_2O_3) and ferric oxide (Fe_2O_3)	10.70	7.54	9.65	10.07	
Calcium oxide (CaO)	64.70	65.35	62.60	63.95	
Magnesia (MgO)	1.60	1.16	1.44	1.33	(d)
Hydraulic modulus	1.98	2.11	1.86	1.97	

[a] Content of plaster = 2 per cent. [b] Not less than 0.75. [c] Within 10. [d] Less than 4.

Each of the cements passed well above all of the requirements, optional or otherwise, of the United States Government specifications for Portland cement as adopted by the Government of the Philippine Islands. They also pass the requirements of the present cement specification of the American Society for Testing Materials. The good results obtained from mixture 2 are of

[4] We regard aëration as the least efficient, practical method of seasoning Portland cement, and recommend grinding in the presence of steam or, better, quenching the hot clinker thoroughly with, or in, water.

special significance, because the materials represented by samples 35, 37, 39 (combined), and 47 are most desirable from the point of view of field relations.

A second series of tests was made which included mixtures similar to 1, 2, and 3, but somewhat modified in composition, and mixture 5 for which limestone 46 was combined with clay 47. The essential characteristics of these four mixtures are given in Table V.

TABLE V.—*Characteristics of second four cement mixtures.*

Mixture No.	Material.	Parts of weight.	Fineness through the 100-mesh sieve.
			Per cent.
5	Limestone 46	100	93
	Clay 47	25	
1a	Limestone 50	100	94
	Clay 48	28.4	
2a	Limestones 35, 37, and 39	100	91.2
	Clay 47	11	
3a	Limestone 35, 37, and 39	100	95
	Clay 51	14	

ULTIMATE CHEMICAL COMPOSITION OF THE VITRIFIED MIXTURES (BY CALCULATION).

Constituent.	Mixture No.			
	5.	1a.	2a.	3a.
Silica (SiO_2)	25.40	23.36	25.30	22.30
Alumina (Al_2O_3)	7.10	5.29	4.06	3.87
Ferric oxide (Fe_2O_3)		5.52	3.04	4.44
Calcium oxide (CaO)	64.50	62.23	63.00	64.40
Magnesium oxide (MgO)	2.06	1.42	1.27	1.52
Hydraulic modulus	2.04	1.86	1.90	2.16

REFRACTORY PROPERTIES.

Mixture No.	Observations.
5	Highest temperature obtainable required to produce well-burned clinker; no fusing and no dusting.
1a	Easily sintered; slight tendency to dust if cooled slowly.
2a	Similar to No. 1 and a little less refractory than No. 2.
3a	Refractory properties better than No. 3, and no tendency to melt or fuse on cooling.

The data in Table V show that in this second series of tests the calculated percentage of calcium oxide was reduced from 63.60 in mixture 1 to 62.23 in mixture 1a and from 64.70 in mixture 2 to 63.00 in mixture 2a and was increased from 62.50 in mixture 3 to 64.40 in mixture 3a. The object of making these modifications has already been stated in the introduction, and the necessity of it will be verified in the discussion of the results obtained.

The essential characteristics of the nonseasoned cements obtained from well-burned clinkers of these mixtures are given in Table VI.

TABLE VI.—*Characteristics of nonseasoned cements obtained from the second series of mixtures.*

Test.	Mixture No.			
	5.	1a.	2a.	3a.
Fineness:	*Per cent.*	*Per cent.*	*Per cent.*	*Per cent.*
Through the 100-mesh sieve	97.4	98.4	98.4	94.8
Through the 200-mesh sieve	86.7	77.8	76.4	75.8
Soundness, in air, water, and steam	sound	sound	sound	sound

SETTING PROPERTIES.

Mixture No.	Plaster added.	Water required for normal consistency.	Initial set.	Final set.
	Per cent.	*Per cent.*	*Hrs. min.*	*Hrs. min.*
5	1	21	1	3
1a	1	21	45	6 15
2a	1	25	Flash set.[a]	
3a	1	27	Flash set.[a]	
5	2	20	2 20	4 20
1a	2	20	2 55	5 55
2a	2	21	30	1 45
3a	2	21	2 35	5 35

[a] See note to Table III.

Experiments on the setting properties of No. 2a showed that the compounds which caused the cement to set were so active and abundant that 3 per cent of plaster and twenty-four hours of thorough aëration were required to produce satisfactory results. The physical properties of No. 2a treated in this manner, and of cements 5, 1a, and 3a, mixed with 2 per cent of plaster and aërated one day, are given in Table VII.

TABLE VII.—*Physical properties of plastered and seasoned cements 5, 1a, 2a, and 3a.*

Test.	No. 5.	No. 1a.	No. 2a.	No. 3a.
Fineness:				
Per cent through the 100-mesh sieve	97.4	98.7	98.8	96
Per cent through the 200-mesh sieve	88.7	78.4	77.2	77
Specific gravity (dried at 100 °C.)	3.13	3.13	3.19	3.16
Per cent water required for normal consistency	21	21	21	21
Soundness in air, water, and steam	[a] sound	[a] sound	[a] sound	[a] sound
Time of setting in hours:				
Initial set	4	3.4	3.2	2.7
Final set	6	6.5	5.4	5.9
Tensile strength in pounds per square inch:				
1-day, neat mortar	505	395	393	477
7-day, neat mortar	650	675	540	735
28-day, neat mortar	695	795	640	765
7-day, 1:3, Ottawa-sand mortar	310	268	232	300
28-day, 1:3, Ottawa-sand mortar	340	320	390	355

[a] The perfect soundness of the steamed pats is shown in Plate I.

The results obtained with No. 5 are as satisfactory in general as those obtained with the first four mixtures. The modified mixtures also produced cements which passed all of the requirements of our standard specifications for Portland cement.

The principal object in testing these modified mixtures was to ascertain the effects of the changes in the hydraulic moduli, and therefore the other conditions of manufacture and testing were maintained as nearly constant as possible. Slight deviations might be expected on account of the unavoidable variations in mixing, burning, and grinding and the personal equation in testing. However, the results showed only slight differences between the physical properties of cements 1 and 1a or between 3 and 3a, and as these were all very good cements the four experiments show that the raw materials used are capable of producing good Portland cement regardless of considerable variation in the hydraulic moduli and unavoidable changes in the conditions of manufacture.

On the other hand, there is a very marked difference between the setting properties of cement 2, which was very satisfactory, and cement 2a, which required 3 per cent of plaster and considerable seasoning. Additional experiments showed that cement 2a, containing 2 per cent of plaster, failed to become desirably slow setting while undergoing thorough aëration for a period of seven days, although the specific gravity fell to 3.09.

Also, the addition of slaked lime in quantities up to 2 per cent failed to retard the set.

The object of adding slaked lime was to ascertain the possible effects of free lime, small amounts of which are present even in the best burned commercial products. It is known that if this lime remains unslaked until the cement is used the heat generated when the water is added will tend to quicken the set. Since, in this instance, small quantities of slaked lime did not retard the set, the presence of free lime could only serve to quicken the setting properties. Consequently, we believe that it would be impossible to control the set of well-burned cements made from the same mixture as cement 2a so that it would remain within desirable limits until used.

We believe that this change from normal to quick-setting properties was due entirely to the reduction in the content of calcareous materials. This conclusion is warranted to some extent by the fact that the same raw materials were used in both instances and by the normal setting properties of the cements (3, 3a, 4, and 5), which were made with either similar limestone or similar clay. However, it required additional data either to verify this conclusion or to prove that good results were dependent upon the conditions of manufacture which produced cement 2. Owing to this and the importance of the raw materials under consideration, we prepared and tested a third mixture (2b) which contained more of the calcareous material than either 2 or 2a.

Mixture 2b was calculated so that the resulting cement would contain about 66 per cent of calcium oxide, thus increasing the hydraulic modulus from 1.86 and 2.15 to 2.31. No difficulty was experienced in burning this high-limed mixture properly, and the well-sintered clinker, pulverized with 1 per cent of plaster to about the same fineness as cements 2 and 2a, gave the excellent results recorded in Table VIII.

TABLE VIII.—*Composition and setting properties of cement 2b.*

Material.	Parts.
Composition of mixture:	
Limestone, equal parts of Nos. 35, 37, and 39	100
Clay 47	7

TABLE VIII.—*Composition and setting properties of cement 2b*—Continued.

Material.	Per cent.
Composition of clinker (calculated):	
Silica (SiO_2)	22.54
Alumina (Al_2O_3)	3.53
Ferric oxide (Fe_2O_3)	3.06
Calcium oxide (CaO)	66.20
Magnesium oxide (MgO)	1.28
Hydraulic index	2.31
Fineness of the cement:	
Per cent residue on the 100-mesh sieve	93.6
Per cent residue on the 200-mesh sieve	78.2
Soundness, 5-hour steam test	sound

SETTING PROPERTIES.

Cement.	Plaster added.	Water required for normal consistency.	Initial set.	Final set.
	Per cent.	*Per cent.*	*Hrs. min.*	*Hrs. min.*
Nonseasoned (sp. gr. = 3.14)	1	21	15	4 00
Do	2	21	2 40	4 50
Aërated for 19 hours (sp. gr. = 3.11)	1	21	3	5
Do	1.5	21	2 00	4 50
Do	2	21	3 35	6

As the setting properties of this higher limed cement proved entirely satisfactory and easy to control, the results obtained with mixtures 2, 2a, and 2b showed that it is necessary to keep the hydraulic modulus within the upper rather than the lower limits if quick-setting products are to be avoided. The combined results also show that the range of permissible variations in the upper limits is sufficiently wide to permit satisfactory factory control in composition.

FINENESS

In Tables III and VII it is recorded that with the exception of 5 the cements were not pulverized nearly as fine as modern grinding machinery has made practicable. The finest ground commercial cements which have come under our observation show about the same residue on the 100- and 200-mesh sieves as No. 5—namely, 2 and 13 per cent, respectively—and our work on the physical and chemical properties of Portland cement proved very

conclusively that such fine grinding is very beneficial because it increases the sand-carrying capacity, permits better seasoning, and increases the constancy in volume after induration. As stated in a previous publication, we believe "that the influence of fineness on the rate of set introduces no new or insurmountable factors into the problem of the control of the set." However, as our conclusions in this respect have not been generally accepted, we reground all of the cements except No. 5, and then subjected them to physical tests, the results of which are recorded in Tables IX and X.

TABLE IX.—*Characteristics of the reground cements.*[a]

Test.	Results.						
	No. 1.	No. 2.	No. 3.	No. 4.	No. 1a.	No. 2a.	No. 3a.
Fineness in per cent:							
Through the 100-mesh sieve	98.6	99.4	99.6	99.6	99.3	99.6	99.6
Through the 200-mesh sieve	86	84.6	85	85.4	85	85.6	85.4
Soundness:							
5-hour steam test	sound	sound	sound	sound	sound	sound	sound
Normal consistency:							
Per cent water required	21	21	20	21	21	[b]28	21
Setting properties:							
Initial set in hours	3	2.60	0.25	1.75	3.20	[b]flash	1.75
Final set in hours	4.25	4.35	1.45	2.45	4.15	[b]flash	4
Tensile strength in pounds per square inch:							
7-day, 1:3, Ottawa-sand mortar	303	317	[c]250	307	320	[c]200	343
28-day, 1:3, Ottawa-sand mortar	366	360	[c]283	335	350	[c]225	369
3-month, 1:3, Ottawa-sand mortar	447	421	[c]392	440	385	[c]330	380

[a] Content of plaster = 2 per cent, except for cement 2a which contained 3 per cent.
[b] See footnote (a) to Table III.
[c] Very erratic development of strength on account of quick-setting properties.

TABLE X.—*Setting properties of cement 3, reground.*[a]

Seasoning.	Per cent plaster added.	Per cent water required for normal consistency.	Soundness (steam test).	Time of setting, in hours.	
				Initial set.	Final set.
None	0.5	21	sound	1.60	3.00
Do	1.0	21	sound	1.75	3.75
Aërated 4 hours	none	20	sound	1.00	5.00

[a] Content of plaster = 2 per cent.

Regrinding caused no undesirable characteristics to develop in

cements 1, 2, 4, 1a, and 3a. Cement 3 became quick setting, but as is shown by the data in Table X its quick-setting properties were easily remedied by either a little additional seasoning or plaster.

Cement 2a became extremely quick setting, but as already stated its setting properties were not satisfactory when it had been pulverized only to an ordinary degree of fineness.

AUTOCLAVE TESTS

It is not thought probable that an autoclave test such as is described in the "specifications for Portland cement" of the Delaware, Lackawanna and Western Railroad Company will be adopted by the United States Government or by the American Society for Testing Materials. However, the data in Table XI make it evident that these raw materials are capable of producing Portland cement which will pass even such severe requirements.

TABLE XI.—*Autoclave tests* [a] *of cements* [b] *1, 2, 4, and 5.*

Test.	Requirements of the D., L. and W. R. R. Co.	Results obtained.			
		No. 1.	No. 2.	No. 4.	No. 5.
Tensile strength in pounds per square inch:					
Neat mortar after 24 hours in moist air.	Not less than 200	507	404	420	505
Neat mortar after autoclave test.	Not less than 500	580	700	596	573
Expansion of neat mortar in per cent.	Not greater than 0.5	0.127	0.104	0.160	0.052

[a] Steam pressure=295 pounds per square inch.
[b] Not reground. The fineness is recorded in Tables III and V.

RELATIVE MERITS OF AVAILABLE RAW MATERIALS

Other conditions being the same, the suitability of a limestone for the manufacture of good Portland cement increases as its chemical composition approaches that of the cement clinker. "Cement rock," which requires little or no additional calcareous or siliceous material, is ideal in this respect, as nature already has prepared a more or less intimately mixed and partially combined mixture which must be produced by artificial means when the limestone is purer. Furthermore, the particles of comparatively pure limestone which fail to combine with siliceous

material remain as free lime,[5] whereas the coarse or underburned particles of cement rock are more apt to possess the more desirable properties of such products as hydraulic limes and Roman cements. However, it should be borne in mind that, as an impure limestone requires less siliceous material than a purer one, the relative cost of quarrying, crushing, and grinding the different raw materials might make it advisable, from an economic standpoint, to use the purest available limestone in spite of these advantages of impurity.

The data in Table I show that the available crystalline limestones 46 and 50 contain only 3.91 and 6.44 per cent, respectively, of clay substance and fluxing materials. Such pure limestones are practically nonfusible, and they must be ground to extreme fineness to enable them to unite thoroughly with the pulverized siliceous materials at cement-kiln temperatures. On the other hand, the coralliferous limestones 35, 37, and 39 are more closely related to cement rock. They contain on the average about 13.2 per cent of clay substance and fluxes, and combine so much more readily with siliceous material that their use is advantageous and involves less danger from free lime and kiln troubles. In addition, they are the most conveniently located and the most easily quarried and pulverized of the calcareous materials. These advantages are especially significant here, because clay 47 is the most conveniently located and desirable of the available siliceous resources.

Clay 47 has the highest content of free silica. Ordinarily, this would be disadvantageous, but in this instance the grain is so fine and the content of total silica so high (70.28 per cent) that, as a whole, the silica content is very satisfactory. Iron in quantities above that required for fluxing purposes is not desirable. Clay 47 contains the least iron, but sufficient to produce, without excessive treatment, a well-burned cement (2b) with a hydraulic index as high as 2.31. Clay 47 can be combined with limestones 46 and 50 to produce good cement, but much more satisfactory results are obtained by combining it with the coralliferous limestones. This is more or less apparent from the data given in Table XII.

[5] The evil effects of free lime and the manner in which it affects the physical and chemical properties of Portland and other hydraulic cements have been thoroughly discussed in previous publications. Cf. Reibling, W. C., and Reyes, F. D., *This Journal, Sec. A* (1910), 5, 117–142; *ibid.* (1911), 6, 207–252; *ibid.* (1912), 7, 135–191.

TABLE XII.—*A comparison of characteristics of cement mixtures, 2, 2a, and 2b with 5 and 5b.*

Mixture No.	Materials.			Fineness.[a]	Hydraulic modulus.	Clinkering properties.	Characteristics of cement		
	Limestone No.	Clay No.	Parts by weight.				Soundness.[b]	Setting properties.	Relative weight.[c]
2	35, 37, and 39 …………	……… 47	100 9	95	2.15	More refractory than 2a, but easily sintered into well-burned clinker. No tendency to melt, and no dusting when the clinker cooled.	Sound	Very satisfactory	360
2a	35, 37, and 39 …………	……… 47	100 11	91.2	1.90	Easily sintered into well-burned clinker at a temperature considerably below the melting point, and practically no tendency to dust.	do	Inclined to be quick setting and rather difficult to control.	390
2b	35, 37, and 39 …………	……… 47	100 7	91	2.31	Sintered into well-burned clinker without difficulty, and no tendency to melt or dust.	do	Very satisfactory	[d] 280
5	46 …………	……… 47	100 25	93	2.04	Highest temperature obtainable required to produce well-burned clinker. No tendency to melt or dust.	do	do	340
5a	46 …………	……… 47	100 29	93.2	1.87	Less refractory than 5, but still rather difficult to burn properly. Clinker dusted considerably even when cooled rather rapidly.	do	Very quick setting and impossible to retard.	([e])
5b	46 …………	……… 47	100 23	92.1	2.17	So refractory that we were not able to obtain a well-sintered product.	Warped and cracked[f]	Satisfactory, but a little erratic.	[g] 245

[a] Per cent through the 100-mesh sieve.
[b] 5-hour steaming test.
[c] 28-day, 1:3, Ottawa-sand mortar.
[d] Nonseasoned.
[e] Very erratic on account of quick setting.
[f] Exposed to the atmosphere in a thin layer for 48 hours before the steamed pat remained sound.
[g] Seasoned until sound.

With the crystalline limestone, a hydraulic index of 2.04 gave satisfactory results although some difficulty was experienced in obtaining a sufficiently high temperature. However, when the index was lowered to 1.87, the clinker dusted and the cement became extremely quick setting, and when the index was raised to 2.17 the mixture became too refractory.

With the coralline limestones, no difficulty was experienced in obtaining good cement from mixtures having hydraulic indices of 1.90, 2.11, and 2.31, and even the last was easier to sinter than 5a, the least refractory of the mixtures, prepared with the crystalline limestone.

In this connection, it is only fair to note that results were obtained with limestone 50 and clay 48 (mixtures 1 and 1a). However, this clay contains 12.05 per cent of iron oxide, 15.04 of alumina, 1.18 of alkalies, and only 52.05 of soluble silica. It is very fusible, and if utilized for the rotary process is apt to cause trouble similar to that described in the following extract of an article by J. G. Dean:[6]

* * * the clay used in manufacturing was low in silica and high in iron oxide and alumina. The Silica-Alumina Ratio

$$\frac{\text{per cent } SiO_2}{\text{per cent } Al_2O_3 + \text{per cent } Fe_2O_3}$$

would average a trifle less than 2.

When pure limestone was used with this clay it was nearly impossible to produce a cement that could be depended on for setting time and tensile strength, and if the lime content of the mix was high enough to burn properly in the kilns the cement would seldom pass the "boiling test."

In order to overcome this defect in the clay, it was necessary to mix the limestone from the upper strata of the deposit, which was siliceous in itself and carried in addition the sand and silt that filtered into it, to the purer stone from the bottom of the quarry. By this haphazard method we were able to keep the Silica-Alumina Ratio high enough to produce a high grade cement.

This method required very careful mixing and grinding, as with cements having a low Silica-Alumina Ratio the limits of variation are extremely narrow. If the lime content is lowered the cement becomes erratic in setting qualities and other peculiarities of over clayed cement. If the lime content is raised the cement will fail on constancy of volume tests and will require "air slaking."

These peculiarities become very complicated with such materials when they have been properly proportioned but improperly ground before burning. * * * The burner will complain of its being "soft" or over clayed. The boiling test on the cement will reveal "free lime" and the tests for setting time and strength will indicate an excess of clay, while the

[6] *Chem. Eng.* (1909), **10**, 52.

chemical analysis will reveal nothing out of the ordinary. * * * [The sieve test] will show that that portion of the mix which was capable of combination was over clayed and the coarse particles of limestone in the mix were burned to "quick lime," consequently the resulting cement displayed the double characteristics of being over clayed and over limed.

No such difficulties would be experienced with a proper mixture of the coralliferous limestones and clay material 47, which latter has a silica-alumina ratio

$$\frac{\text{per cent } SiO_2}{\text{per cent } Al_2O_3+\text{per cent } Fe_2O_3}$$

which averages a trifle less than 5 and is sufficiently low in lime and alkalies to possess desirable refractory properties.

ROTARY VERSUS STATIONARY KILNS

Provided that financial considerations permit, we strongly favor the installation of rotary, rather than stationary, kilns. Underburning is fatal to the efficiency of Portland cement, and while with these raw materials there would be no necessity of producing soft-burned clinker if the rotary process was used the best stationary kilns would yield a considerable amount of underburned cement. In fact, the product of a set kiln, unless well sorted at considerable expense, would not be true Portland cement but a mixture of seasoned, underburned, and well-burned cements containing sintered, nonsintered, and hydrated free lime and fused and sintered compounds of many kinds.

However, we made a few tests of underburned clinkers obtained from some of the mixtures already described, and the results obtained are recorded in Table XIII.

TABLE XIII.—*Characteristics of decidedly underburned cements seasoned until sound.*

Test.	Results.			
	No. 2.	No. 2b.	No. 3a.	Average.
Specific gravity	2.94	2.95	2.95	2.95
Time of setting in hours:				
Initial set	1.25	1.85	0.85	1.30
Final set	6.75	8.45	6.90	7.40
Tensile strength in pounds per square inch:				
7-day, 1 : 3, Ottawa-sand mortar	212	189	177	193
28-day, 1 : 3, Ottawa-sand mortar	220	170	180	190
3-month, 1 : 3, Ottawa-sand mortar	325	315	322	321

It is evident[7] that the well-burned clinkers could be mixed with considerable of the underburned product, and yet, if properly seasoned, produce Portland cement which would pass all the requirements of our standard specifications.

NATURAL (OR ROMAN) CEMENT

In a previous publication of the Bureau of Science[8] we called attention to the possibility that the present and near future resources and the commercial and economic conditions of these Islands might favor the manufacture of what may be called an artificial natural, or Roman,[9] cement.

Natural cements are largely used in America because of their cheapness. They harden more rapidly in air or water than hydraulic lime, but generally speaking they lack uniformity in strength, setting properties, and constancy of volume to a much greater extent than Portland cements. This is due largely to the present universal practice of burning cement rock in set kilns under which conditions considerable variations in chemical composition and both under- and overburning are unavoidable.

To produce a more desirable cement of this class in the Philippines, we advocate the method of producing an *artificial* Roman cement by blending ground calcareous and siliceous materials in the proper proportion and then burning the mixture in a rotary kiln at a temperature of about 1,000° C. By this method the chemical composition and the degree of burning could be uniformly regulated and a cement of definite physical properties produced. It might not be a feasible method in countries where the cost of the production of Portland cement is low, but the high cost of imported coal and Portland cement in the Philippines would overcome this objection and especially since local coals could be utilized for burning the natural cement.

We prepared and burned several of such artificial Roman cement mixtures, and the results obtained showed conclusively that the method could be adopted with good results. We had time and opportunity to make only a very preliminary study of the possibilities of the raw materials in this respect, but even so obtained several cements which passed all of the requirements of the American Society for Testing Materials for natural cement, even though we used heavily clayed and, consequently, easily burned mixtures. The data in Table XIV show that these

[7] Cf. *This Journal, Sec. A* (1910), **5**, 117–142.
[8] *This Journal, Sec. A* (1913), **8**, 135–195.
[9] Bleininger, A. V., *Bull. Geol. Surv. Ohio* (1904), **4**, 186.

raw materials are capable of producing natural cement with a cementation index as high as 2.47 and still pass the requirements of specifications in spite of the fact that such products become feebler as this index rises above 2.

TABLE XIV.—*Characteristics of artificial Roman cement "I" obtained from Naga raw materials.*

MIXTURE BURNED AT 1,000° C.							
Material.	Parts by weight.	SiO_2.	R_2O_3.	CaO.	MgO.	Loss by ignition.	Cementation index.
Coralline limestone	100	9.34	2.94	47.38	0.89	35.90	
Clay 51	100	41.97	18.20	15.12	2.16	19.45	
Mixture	200	51.31	21.14	62.50	3.05	55.35	
Per cent	100	25.65	10.57	31.25	1.52	27.68	[a]2.47

CEMENT.		
Test.	Result.	Requirement of specifications.[b]
Time of setting:		
Initial set in minutes	30	(c)
Final set in hours	3	(d)
Tensile strength in pounds per square inch:		
Neat mortar, 7 days	167	150
Neat mortar, 28 days	262	250
Neat mortar, 3 months	300	(e)
7-day, 1 : 3, Ottawa-sand mortar	148	50
28-day, 1 : 3, Ottawa-sand mortar	330	125
3-month, 1 : 3, Ottawa-sand mortar	385	(e)

[a] $\dfrac{2.8 \times \%SiO_2 + 1.1 \times \%Al_2O_3 + 0.7 \times \%Fe_2O_3}{\%CaO + 1.4 \times \%MgO}$

[b] *Am. Soc. Test. Materials* (1912).

[c] Not less than 10.

[d] Not more than 3.

[e] Not given.

CONCLUSION

The results obtained by this investigation are regarded as conclusive proof of the following:

1. The raw materials which are available in the vicinity of Naga, Cebu, are eminently suitable for the commercial manufacture of high-grade Portland cement.[10]

[10] Plate II, figs. 1 and 2, are photographs of raw materials from Naga, Cebu, and samples of Portland and Roman cement and concrete which they produced. These products formed part of the exhibit of the Bureau of Science of local calcareous-siliceous resources at the 1914 Philippine Exposition.

2. The raw materials represented by coralline limestones 35, 37, and 39 and tuff 47 constitute the most desirable of the available resources. This is especially true as, in addition to their high merits with respect to manufacturing efficiency, their use would reduce the cost of quarrying, transportation, and grinding to a minimum.

3. Proper mixtures of these two raw materials produce cements which are comparatively high in silica and low in alumina, and for best results the hydraulic modulus

$$\frac{\text{per cent } CaO + \text{per cent } MgO}{\text{per cent } SiO_2 + \text{per cent } R_2O_3}$$

should be kept within the higher (2 to 2.3) rather than the lower (1.8 to 2) limits. Owing to the presence of a very desirable quantity of fluxing materials, the high-limed mixtures have ideal sintering properties and the use of less siliceous materials is not desirable, much less necessary.

4. Contrary to a somewhat general belief, it is not characteristic of Portland cements as high in silica and low in alumina as proper mixtures of these raw materials to harden too slowly. On the contrary, they are very apt to be extremely quick setting if the hydraulic modulus is low.

5. These raw materials are capable of producing satisfactory, *artificial* natural (or Roman) cement, and as the clay content can be carried very high with good results the commercial production could be accomplished at a minimum expense.

Incidentally, this work demonstrates many important principles involved in testing raw materials, and the results obtained add corroborative evidence to our published observations and conclusions concerning the physical and chemical properties of Portland cement and specifications and methods for their purchase.[11]

[11] Reibling, W. C., *This Journal, Sec. A* (1913), 8, 107–124.

ILLUSTRATIONS

PLATE I

Steamed pats of nonseasoned cements 1, 2, 3, 4 (Table IV), 5, 1a, 2a, and 3a (Table VII), showing perfect soundness.

PLATE II

FIG. 1. Naga, Cebu, raw materials, and the resulting Portland clinker, cement, and concrete exhibited at the 1914 Philippine Exposition. 1/8 actual size.

2. Naga, Cebu, raw materials and the resulting Roman clinker, cement, and concrete exhibited at the 1914 Philippine Exposition. 1/8 actual size.

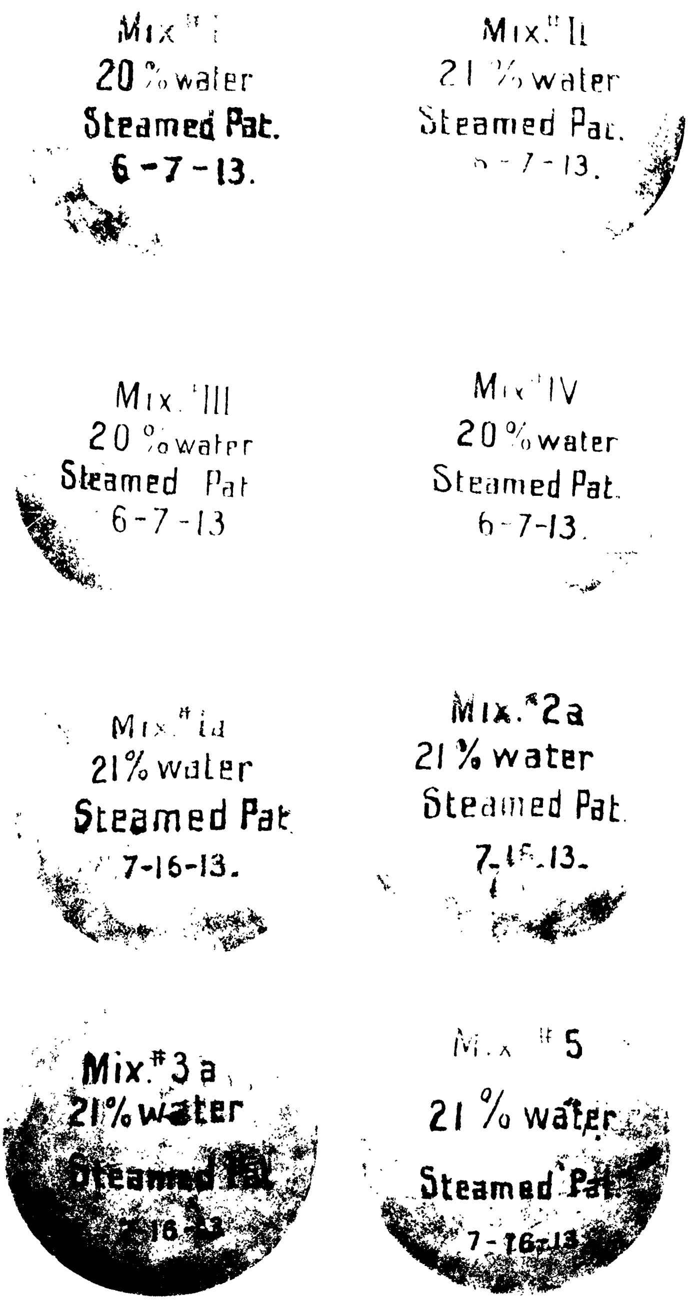


PLATE I. SOUNDNESS PATS OF NAGA CEMENT AFTER FIVE-HOUR STEAMING TEST.

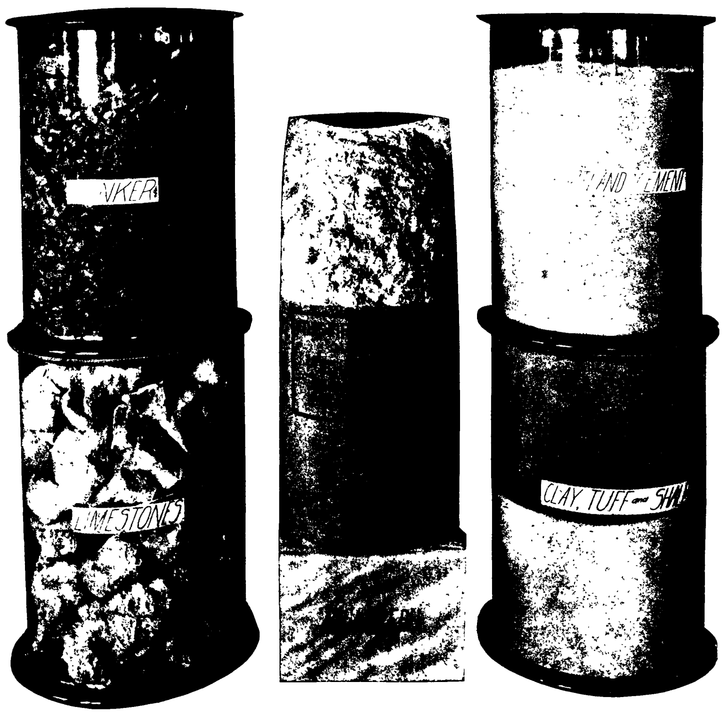


Fig. 1. Raw materials from Naga, Cebu, and the Portland clinker, cement, and concrete produced.

Fig. 2. Raw materials from Naga, Cebu, and the Roman clinker, cement, and concrete produced.

PLATE II.

GEOLOGY AND FIELD RELATIONS OF PORTLAND CEMENT RAW MATERIALS AT NAGA, CEBU

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One plate and 3 text figures

INTRODUCTION

In 1911 the Bureau of Science undertook to investigate the possibilities of manufacturing Portland cement in the Philippine Islands somewhat more comprehensively than had been attempted previously, and began the work with a study of the geology and field relations of the raw materials. The possible manufacturing sites which had been discussed by previous investigators [1] and all other districts where the requisite calcareous and siliceous materials had been encountered under conditions at all favorable as to the factors of transportation, fuel, and markets were included in this study. Samples were collected for subsequent chemical examination and experimental burning tests.

A general statement of the results of the geologic investigation was published in 1912,[2] and the vicinity of Naga, Cebu, was noted as one of the possible sites which were considered most favorable. The central position of Naga in the Archipelago throughout which the product could be marketed and the proximity of the raw materials to railroad and harbor facilities and to fuel in an adjacent coal field were found to be the principal advantages of this site, apart from the unusual suitability of the raw materials themselves. The raw materials from Naga have been burned to a superior Portland cement both by testing laboratories in the United States and in the Bureau of Science,[3] and the geology and field relations at Naga are taken up in this paper to supplement these data.

SITUATION

The proposed manufacturing site is on the southeastern coast of Cebu, at the mouth of Pandan River, a small stream which empties into the sea near Naga. The Philippine Railway crosses

[1] Cox, Alvin J., *This Journal, Sec. A* (1909), **4**, 211; *ibid.* (1908), **3**, 391.
[2] Pratt, Wallace E., *Min. Resources P. I. for 1911* (1912), 82.
[3] Reibling, W. C., and Reyes, F. D., *This Journal, Sec. A* (1914), **9**, 127.

the site, and offshore is a small protected harbor, designated as Tinaan Anchorage on the maps of the Coast and Geodetic Survey (fig. 1). At the head of Pandan River, 12 kilometers from the coast, is the Uling coal field which could probably be utilized to supply fuel for a cement plant. The coal is of suitable quality, and there is no special difficulty in the way of locating a railway along the valley of Pandan River. A wide alluvial plain has developed at the mouth of Pandan River and along its lower course except where the valley cuts through Magdagoog Range, a ridge trending parallel to the coast at a distance of about 2 kilometers inland. Mount Magdagoog from

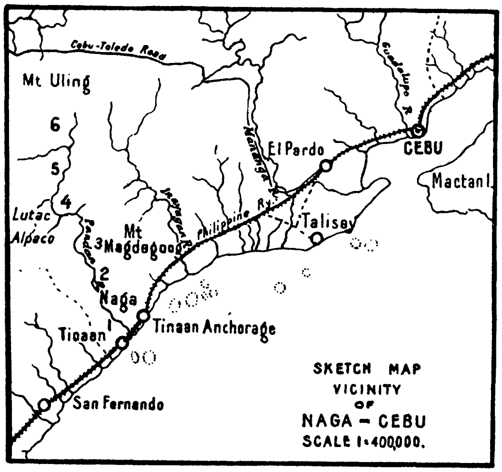

FIG. 1. Outline map of the vicinity of Naga, Cebu. (1) Location of limestones 35, 37, and 39; (2) limestone 46 and tuff 47; (3) clastic rocks 48 and 49; (4) limestone 50; (5) shale 51; (6) upper limestone in coal measures.

which this ridge takes its name lies about 3 kilometers north of the plant site, and attains an elevation of nearly 400 meters.

GEOLOGY, CHARACTER, AND FIELD RELATIONS OF THE RAW MATERIALS

General.—The formations represented in section in fig. 2 comprise the usual Philippine sedimentary column. The paleontologic studies of Abella,[4] Martin,[5] and (in more detail) of Smith[6] make it reasonably certain that the greater part of the section consists of rocks of Miocene and Post-Miocene age. On

[4] La Isla de Cebu. Madrid (1886).

[5] Ueber tertiäre Fossillen von den Philippinen. Translation by George F. Becker. *21st Annual Rep. U. S. Geol. Surv.* (1895), 129–140 of reprint.

[6] *This Journal, Sec. A* (1913), **8**, 235 et seq.

the lower flanks of a cordillera made up of Pre-Oligocene igneous and metamorphic rocks are the upturned edges of sedimentary beds which dip away from the axis of the cordillera on both sides. Both the trend of the cordillera and the general strike of the sedimentary rocks are north 20° east. West of the cordillera is the Miocene series in which the Uling coal occurs, while beds of tuff and limestone, more recent than the coal measures, are encountered in considerable thickness on the eastern flank of the igneous-metamorphic complex.

The coal-bearing rocks consist of a basal conglomerate overlain in turn by limestone, shales, fine-grained clastic rocks, alternating shales and sandstones, and an upper limestone. Three coal seams varying from 1 to 5 meters in thickness are intercalated

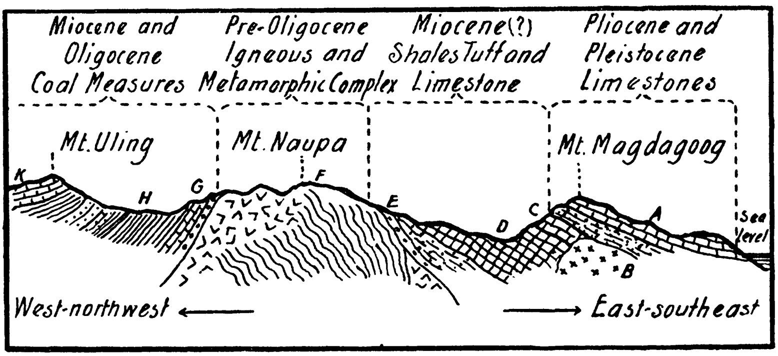

FIG. 2. Diagrammatic cross section from the southeastern coast of Cebu to Mount Uling; length of section, 8 kilometers. (A) Limestones 35, 37, and 39; (B) andesitic agglomerate; (C) limestone 46; (D) tuff 47; (E) conglomerate, shale, etc.; (F) clastic rocks 48 and 49; (G) limestone 50; (H) shale 51; (K) upper limestone of coal measures.

with the alternating shales and sandstones, while a single seam about 1 meter in thickness is found in the basal conglomerate. The lowest member of the sedimentary series on the eastern flank of the cordillera is also a conglomerate which is associated at places with limestone, but no coal-bearing series overlies these rocks; instead, are about 100 meters of shales, sands, and clastic rocks overlain in turn by tuffs, limestones, volcanic agglomerate, and at the top of the series by other limestones. These most recent limestones are of Pliocene and Pleistocene age according to Abella,[7] and they are of widespread occurrence along the entire coast line of Cebu. They are important as cement raw materials, and samples 35, 37, and 39 are representative of them at the proposed manufacturing site.

[7] *Loc. cit.*

Calcareous materials 35, 37, and 39.—The Pliocene and Pleistocene limestones form a terrace which rises abruptly from sea level at the coast to an elevation of about 30 meters and thence continues inland at a gentle slope to the crest of Magdagoog Range (Plate I). The upper or latest portion consists of fragmental coral in beds which dip very gently toward the coast and do not persist inland more than 1 kilometer. Mingled with the coral in different beds (fig. 3) are marine shells, coral sand, chalky limestone, and a fine conglomerate of various other rocks. Parts of the beds are entirely coralline, and the corals often remain almost intact in the position assumed during growth, but more generally the rock consists of large and small fragments of coral in utter disorder. Evidently the formation resulted from the intermingling of fragments eroded from adjacent raised coral reefs and of material carried down

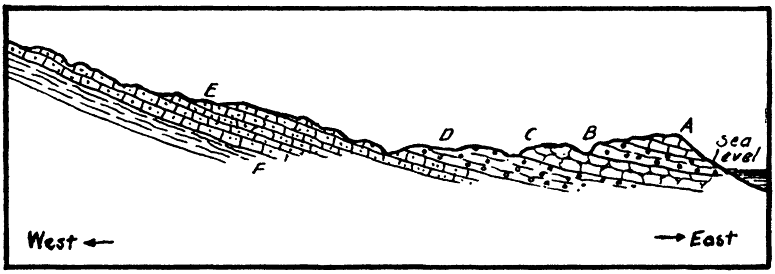

FIG. 3. East-west geologic section through limestones 35, 37, and 39, Naga, Cebu; length of section 1,500 meters. (A) Coralline limestone; (B) coral shells and fine conglomerate; (C) fragmental coralline limestone; (D) coralline limestone and fine conglomerate; (E) chalky limestone; (F) calcareous, sandy clay.

periodically from farther inland, with growing coral near the shore line.

Beneath the fragmental coral beds, the maximum aggregate thickness of which is perhaps 60 meters, is a soft yellowish gray limestone very much like chalk in character. A few hundred meters inland where the upper beds, by reason of their tendency to thin out, are no longer encountered, the chalky limestone is exposed without overburden at the surface. The material is uniform, and occurs in heavy beds with a total thickness of about 30 meters. Minute fossil forms are to be observed, but the character of the grains is essentially that of very finely divided, amorphous calcium carbonate with accompanying traces of clay. This uniform extreme fineness of grain makes it appear improbable that the chalk originated as coral sand; a more plausible suggestion is that it represents

an accumulation of chemically precipitated calcium carbonate or, possibly, of very small, lime-secreting marine organisms.

It would be possible to quarry these limestones advantageously from either of two sites. From the bluff near the beach at Tinaan, fragmental coral with the composition represented by the combination of 35, 37, and 39 (Reibling and Reyes) could be secured in adequate quantity. The quarry face would be 14 to 25 meters high, and the excavation could proceed readily over an area of some 20 hectares, making available at least 5 million metric tons of material. The present annual consumption of cement in the Philippines is between 300,000 and 400,000 barrels, while this estimated supply of limestone would permit the manufacture of 500,000 barrels of cement annually for fifty years.

The alternative quarry site is in the beds of chalk, at a point along the west wall of Pandan Valley about 800 meters from the coast. From this site a supply of material equal to, or greater than, the foregoing estimate could be obtained under most economical conditions. The quarry face would be about 30 meters high, and there would be no overburden to remove since the overlying beds do not extend so far inland (fig. 3).

More than fifty samples have been taken from the two proposed quarry sites and submitted to chemical analysis. The greater number of these samples were obtained as cuttings from drill holes. The test holes, which were 5 centimeters in diameter and varied from 6 to 18 meters in depth, were drilled with a hand drill consisting of a steel chisel-shaped bit joined to a drill rod of 1-inch gas pipe. The cuttings were removed from the hole by means of an earth auger (in some materials a simple sand pump was necessary) attached to the drill rod in place of the bit.[8]

The fragmental coral beds at the quarry site nearest the coast are not uniform chemically; the average composition lies between the limits shown by samples 35 and 39, and several samples

[8] Hand churn drills of this type for prospecting moderately hard formations have been described by many writers. They are cheap, easily constructed, and surprisingly effective. Four Filipinos can operate such a drill to good advantage. On the work at Naga, each crew was provided with a tripod made of three 6-meter lengths of bamboo, which was set up over the hole and used to support the lengths of drill rod as they were withdrawn. With such a tripod the drill rod need be disconnected only at from 10- to 12-meter intervals, and much time is saved which would otherwise be lost in disconnecting more frequently and in handling the heavy tubes as they are drawn from the hole and laid on the ground or lifted from the ground to be reconnected.

varied more widely than these two in composition. The chalk at the second quarry site is more uniform, and the composition of every sample taken from this site is very close to that of 37 or 39. The material at both sites is closely similar to a raw mixture for Portland cement in composition; the fragmental coralline limestone contains from 10 to 14 per cent of silica and from 3 to 5 per cent of iron and aluminum oxides, while the chalky limestone contains from 7 to 9 per cent of silica and about 3 per cent of iron and aluminum oxides. Neither material contains more than 1 per cent of magnesia.

Something of the relative ease of quarrying these limestones is to be inferred from the experience of the district engineer at Cebu. Such rocks have been classed as "soft rock excavation" in the specifications for practically all engineering work involving excavation in them. Contractors have found it advantageous in several cases to remove such material by pick and shovel without the use of powder. In Portland cement manufacture the coarse crushing of these materials should also be accomplished cheaply because of their softness and naturally fine grain. The cost of fine grinding, on the other hand, might be slightly higher than usual since chalk is less brittle than the crystalline limestones which are commonly used in making Portland cement.

Calcareous material 46.—Sample 46 represents a bedded, crystalline limestone which outcrops in the western base of Mount Magdagoog on Pandan River about 2 kilometers from the coast. This limestone is stratigraphically lower than the rocks just described, and between it and the chalky limestone some 50 meters of calcareous sandy clay and a considerably greater thickness of volcanic agglomerates intervene. The agglomerate forms the core of Magdagoog Range, and is exposed in the cañon of Pandan River. Limestone 46 appears to stand on edge in the most clearly defined exposures, and the strata are much broken.

In composition, 46 is a fairly pure limestone; the ratio of silica (3.1 per cent) to iron and aluminum oxides (2.2 per cent) is less than in the more readily available limestones near the coast. The small number of samples which have been taken show moderate uniformity in chemical composition. The limestone is available in an adequate quantity, and is encountered along the route of the proposed railroad from the mill site to the Uling coal field, as are all the other materials considered.

Calcareous material 50.—Sample 50 is a crystalline and relatively pure limestone, which is interbedded in the base of the coal measures and lies inland about 7 kilometers from the

coast along Pandan River. It contains numerous foraminifera, and is referred by Smith [9] to the Oligocene. The limestone is bedded, with a total thickness of some 10 meters, and dips at a high angle to the west. As in the case of limestone 46, it has not been thoroughly sampled but appears to be fairly uniform in composition with about 2.0 per cent of silica and 1.5 per cent of iron and aluminum oxides as the principal impurities. Although it is at a considerable distance from the coast and the cost of quarrying would be high on account both of the hardness of the rock and the limited width over which the quarry face could be extended because of the steep dip of the beds (fig. 2), limestone 50 can be obtained in adequate quantity and is therefore considered as an available calcareous raw material.

The upper limestone in the coal measures which occurs at an elevation of from 550 to 650 meters on Mount Uling, on the other hand, is so far from any railroad that would be built to bring the coal down to the coast that it may be considered inaccessible and therefore not available for cement manufacture.

Siliceous material 47.—Sample 47 represents an extensive and exceedingly regular formation made up of very fine volcanic tuff or ash which is indurated into a moderately hard, light-colored rock of fine grain and splintery conchoidal fracture. Bedding planes are not clearly defined, but numerous minor joints pass through it.

The tuff lies stratigraphically below [10] limestone 46 and in close proximity to the andesitic agglomerate in Magdagoog Range; underlying it in turn are the shales, sands, and conglom-

[9] Doctor Smith studied thin sections of this rock, and his notes indicate that the conspicuous fossil casts in it are very similar to, if not identical with, *Heterostegina margaritata,* which according to L. Schlumberger [Note sur un Lepidocyclina nouveau de Borneo in *Samm. d. geol. Reichsmus. in Leiden* (1902), I, 6, pt. 3] was found by K. Martin in the Oligocene at Dax (France ?).

[10] It is not clear whether the tuff is related in origin to the andesitic agglomerate in Magdagoog Range or not. In fact; there is doubt as to the relative age and the manner of origin of the agglomerate which is breccia-like in some exposures and appears to surround or inclose a core of massive andesite. The apparent metamorphism and disturbance in the crystalline character and upturned beds of limestone 46 and in the indurated, closely jointed structure of the tuff could be explained by assuming that the andesite was of intrusive origin and had forced itself up through these rocks subsequent to their deposition. Evidence of local thermal action may be deduced from the presence of hot mineralized springs in the andesite at the barrio of Mainit. Apparently the andesite may have resulted from volcanic activity which yielded alternately flows and coarsely fragmental ejecta at a

erate which rest upon the eastern flank of the cordillera. It can be quarried under favorable conditions at Pandan, a little more than 2 kilometers from the coast. At this site a quarry with a face 30 meters high on the average could be advanced over an area of about 16 hectares. It has been noted that the composition of the coast limestones would require very little modification in cement manufacture; as a matter of fact, from 5 to 7 parts of tuff are sufficient for 100 parts of limestone. On this basis of calculation, there is available several times the quantity of tuff required for combination with the total supply of limestone at the mill site. Quarrying the tuff would not be expensive because, although it is moderately hard, it is easily shattered and broken up and there is no overburden to be removed.

In chemical composition the tuff is unusually constant. The average analysis shows 70 per cent of silica, 12 per cent of alumina, from 1 to 2 per cent of iron oxide, 4 per cent of alkalies, and 2 per cent of lime as the principal constituents. In 20 analyses of drill-hole samples from widely separated points, silica ranges from 67 to 72 per cent, and in 10 of these it lies between 69 and 71 per cent. In spite of the high content of silica, the tuff is very easily fusible due perhaps to the large content of volcanic glass which is present.

Siliceous materials 48 and 49.—The shale-sand-conglomerate series beneath the volcanic tuff rest upon the Pre-Oligocene complex of igneous and metamorphic rocks which are exposed at the surface in the mass of the cordillera. Various basic igneous rocks, a majority of which are of the deep-seated type, as well as schists and gneisses are encountered in this part of the section, but the predominant rocks are slightly metamorphosed clastics or arkoses, which appear to have been derived from a closely adjacent land area—one consisting perhaps of the

time subsequent to the deposition of the tuff represented by sample 47, or it may be conceived of as an intrusion, the outer shell of which has been rendered fragmental by movement during cooling. Although the tuff appears to lie at a horizon lower than that of the agglomerate in the Pandan section, yet elsewhere in Cebu the same rocks occur in reversed stratigraphic position; that is, the tuff overlies the agglomerate or breccia. Whether the andesite is extrusive or intrusive, it appears in either case to be of local origin, while the uniformity and extent of the tuff suggest that it is a widespread formation. The chemical compositions are quite different, too, the tuff carrying considerably more silica than the andesite. On the other hand, the two classes of rock are inevitably closely associated, and in an exposure near Iligan, a barrio of Toledo, there appears to be a continuous gradation between the two types.

primary rocks with which the clastics are associated. Abella spoke of these rocks as "tobas" (tuffs), a term which he seems to have used to denominate secondary rocks closely associated with an igneous type from which they were derived, partly by erosion and partly perhaps by residual decomposition.

Samples 48 and 49 represent earthy clastic rocks of nonuniform grain size, from different horizons in this formation. They were obtained on Pandan River about 6 kilometers inland, from rocks which are imperfectly bedded, much crumpled, and slightly schistose in some exposures. The clastic rocks are not ideal cement raw materials; the few analyses which have been performed show that the composition is not uniform, silica varying from 58 to 60 per cent, iron oxide from 5 to 12 per cent, and alumina from 13 to 19 per cent. Their physical character is likewise objectionable because of the coarse and nonuniform grain size and the incipient schistosity. They are available in enormous quantity, however, and in as much as the coast limestones require so little clay that any change of composition in the clay would change the composition of the entire cement mixture to a much lesser degree they were considered as possible siliceous materials.

Siliceous material 51.—The shale (sample 51) which predominates in the coal-bearing rocks is a bedded deposit of uniform physical character and very fine grain. The most convenient quarry site in this material is at Buntun on Pandan River about 9 kilometers from the coast. More than an adequate quantity is available, and could be quarried cheaply since the shale is relatively soft. As with the clastic rocks, however, the chemical composition of this material appears to be variable. In view of the rather high content of silica in the coast limestones, the shale might prove useful on account of the low ratio of silica to alumina plus iron oxide (silica, 42 per cent; alumina plus iron oxide, 18 per cent).

CONCLUSIONS

The coast limestones, represented by samples 35, 37, and 39, are preferable to any other available calcareous material by reason of their favorable situation, their softness, the nearly horizontal position of the beds, the absence of overburden, and their close approach to the desired raw mixture in chemical composition. The chalk, which has the composition of sample 37 or 39, is preferable to the fragmental coral with the average composition of 35, 37, and 39, because of its greater uniformity

in chemical composition and in fineness of grain. On the other hand, the chalk requires slightly more clay for a proper cement mixture, and must be hauled a short distance (600 meters) to the mill site while the other rock lies practically on the mill site. Good cements have been made from each class of material and from mixtures of the two classes of material.

Limestone 46 must be transported about 2 kilometers; it is hard, and quarrying relations are not favorable. Owing to its composition, a large proportion of clay materials must be added to it to produce a Portland cement raw mixture. Because of this requirement, limestone 46 cannot well be used with tuff 47 which is too siliceous to be added in large proportion to a cement raw mixture, and since tuff 47 is the most desirable of the available clay materials limestone 46 cannot be considered as favorably as limestones 35, 37, and 39 which can be used with tuff 47. The same objections may be made to the use of limestone 51, with added emphasis as to unfavorable quarrying relations and as to the length of the required haul, which in this case would be about 7 kilometers.

Siliceous material 47, a volcanic tuff, is preferable to the other siliceous materials by reason of the shorter transportation which its use would involve and the uniformity in its physical and chemical character. It could be quarried as cheaply as either of the other available siliceous materials, and for use with the best calcareous materials its composition is at least equally suitable. Siliceous materials 48 and 49, which are clastic sediments, are objectionable chiefly because of their nonuniform chemical and physical characters. The expense of quarry operation would be about equal to that required for material 47, but the cost of transportation would be greater because material 47 is less than half as far from the proposed mill site. Siliceous material 51, a shale, is constant in physical character but varies in chemical composition. Like materials 48 and 49, it would be quarried cheaply, but it is at an even greater distance (9 kilometers) from the mill site.

The experimental results of Reibling and Reyes show that calcareous materials 35, 37, and 39 and siliceous material 47, which are considered most favorable from the viewpoint of field relations, are likewise most desirable from the viewpoint of ease of manufacture and excellence of the product. This being the case, the other materials tested lose their importance, while at the same time the feasibility of cement manufacture at Naga is established both by the study of the field relations and the burning tests on the raw materials.

ILLUSTRATIONS

PLATE I

(Photograph by Pratt)

Portland cement raw materials near Naga, Cebu. Alluvial clay flood plain of Pandan River in foreground, terraces of coralline and chalky limestones in distance.

TEXT FIGURES

PLATE I. PORTLAND CEMENT RAW MATERIALS NEAR NAGA, CEBU; ALLUVIAL CLAY FLOOD PLAIN OF PANDAN RIVER IN FOREGROUND; TERRACE OF CORALLINE AND CHALKY LIMESTONES IN DISTANCE.

NATURAL CEMENT VERSUS BRICK; IWAHIG PENAL COLONY RAW MATERIALS

By W. C. Reibling

(*From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.*)

One plate

INTRODUCTION

Although this investigation deals primarily with the value of certain raw materials which are available for the manufacture of brick and natural cement at the Iwahig penal colony, many of the results obtained and the principles discussed are universal, as well as local, in their significance and value. This is especially true of the data on the manufacture of natural cement by the so-called artificial process.

Results obtained by using fine coral sand as the calcareous material, while especially interesting to this country, are none the less valuable to the cement industry in general. They show the economic possibilities not merely of the Iwahig sand, but also of vast resources of similar coral and calcareous sands which heretofore have been practically overlooked by cement producers although already ground fine by natural forces. The artificial method of manufacturing natural (or Roman) cements is comparatively new, although advocated by A. V. Bleininger[1] many years ago as a practical method of overcoming the lack of uniformity in the setting and hardening properties of natural cements.

BRICK MANUFACTURED AT IWAHIG

The history of the manufacture of brick at the Iwahig penal colony shows that the industry was started at the suggestion of Governor Evans. He had experience with brick making at Bontoc, and believed that successful results could be obtained with the clay located a short distance from the colony on the banks of Iwahig River. The Iwahig bricks are made from an alluvial clay obtained near the junction of Malatgao and Iwahig Rivers adjacent to the penal colony. At first, the clay was pugged by a homemade mill turned by a carabao, and the bricks were molded by hand. Now, the clay is taken directly

[1] *Bull. Geol. Sur. Ohio* (1904), 4, 186.

from the ground, mixed with water, and compressed in molds by an animal-power Henry Martin machine. The clay is taken from not less than half a meter below the surface to exclude loam as much as possible, and water is added until a mud ball dropped 45 centimeters will flatten but not crack. No sand is used except for the purpose of sanding the molds so that the green bricks can be removed without difficulty. The bricks are "hacked" as soon as they are dry enough to withstand handling, and finally they are burned in a kiln 45 meters long, 3 meters high, and 2.5 meters wide. Wood fuel is used, and a white heat is maintained for a continuous period of at least twelve hours.

The appearance of the finished product is shown by bricks 1 and 2 in Plate I, fig. 1. No. 1 shows the appearance of the cut surface which, owing to the extreme stickiness of the clay when pugged to the consistency practiced at Iwahig, is deeply pitted and ruptured. The sanded sides shown by brick 2 are fairly smooth, but the white coral sand used for sanding the molds gives the brick a very unpleasing appearance. Also, since the sand is highly calcareous, it is converted into caustic lime which, upon subsequent hydration, slakes and, in expanding, destroys the original smoothness of the surfaces. Also, there is some pitting and abrasion due to the slaking of nodules of lime beneath the surface. It is suggested that the use of molding sand might be avoided and the appearance of the brick improved in consequence if the molds were merely dipped in water instead of being sanded.

The physical properties of bricks 1 and 2, which are given in Table I, are characterized by excessive porosity, poor strength, and high absorption.

TABLE I.—*Physical properties of the brick manufactured at the Iwahig penal colony.*

Item.	Brick. No. 1.	Brick. No. 2.
Dimensions in centimeters	20.3×9.2×5.4	20.5×9.7×5.5
Weight in grams (dry)	1,731	1,883
Apparent density (weight/ volume of brick)	1.69	1.71
Specific gravity	2.91	2.94
Absorption of water in per cent	20.61	20.22
Modulus of rupture:		
Transverse strength in pounds	1,050	970
Distance between supports in inches	6.0	6.0
$3Pl/2bd^2$	339	274
Crushing strength in pounds per square inch	779	701

It was thought that a study of the physical and chemical properties of the clay might reveal a practicable method of improving the quality of the brick, and finally at the suggestion of the Director of the Bureau of Science a representative sample was forwarded to the Bureau of Science.

The clay, which is a dirty brown in color and lightly specked with white particles, many of which prove to be grains of coral sand, was first subjected to a chemical examination. The results obtained are recorded in Table II.

TABLE II.—*Chemical characteristics of Iwahig clay (dried at 110° C.).*[a]

ULTIMATE CHEMICAL CONSTITUENTS.

Constituent.	Per cent.
Loss by ignition	10.70
Total silica (SiO_2)	42.16
Soluble silica	9.40
Alumina (Al_2O_3)	24.26
Ferric oxide (Fe_2O_3)	13.90
Calcium oxide (CaO)	6.40
Magnesium oxide (MgO)	0.90
Sodium oxide (Na_2O)	1.41
Potassium oxide (K_2O)	0.10
Sulphur trioxide (SO_3)	0.20
Carbon dioxide (CO_2)	....
Total fluxes	22.75
RATIONAL ANALYSIS.	
Feldspar	31.38
Quartz	21.02
Clay substance, about	42.00

[a] Analyzed by F. Peña, chemist, Bureau of Science.

The high content of iron and calcium oxide and the low content of silica indicate that the clay has little or no value for the manufacture of hard-burned ware, such as paving brick. Experiments showed that it burned best at a temperature of about 1,050° C. Stiff-mud briquettes, burned at this temperature in an oxidizing atmosphere, showed a tensile strength of about 230 pounds per square inch and were of an agreeable brick red.

Except for the few particles of coral, the clay contains very little sand that is visible to the naked eye. It is easily pulverized, and for best results the nodules of coral should be disintegrated or separated from the clay by sifting or elutriation although the clay does not contain more than 1.2 per cent of such material.

The round ruptured spot near the top of brick 5 and the cracks on the surface of brick 6, as seen in Plate I, fig. 1, show the undesirable effects of nodules of calcareous material in the clay. For

brick 7, the pulverized clay was screened through a 30-mesh sieve and the surfaces remained free from rupture.

Ground until no residue remains upon the 20-mesh sieve, or finer, the clay is easy to pug, and when mixed with about 24 per cent of water produces a stiff mud which is easy to mold by hand or to express smoothly through an ordinary brick die. The addition of more water tends to produce a soft mud which is too sticky and too lean to mold well in any single process. If molded by pressure in the semidry or dry state, the brick disintegrates with even ordinary handling or it cracks and warps while drying or burning. The hand-molded, stiff-mud bricks dry fairly rapidly, and in so doing shrink about 8 per cent and develop a tensile strength of 133 pounds per square inch; but better density, strength, and appearance can be obtained by first molding the stiff mud by hand or by expression, and after most of the shrinkage has taken place re-pressing it at a pressure of about 1,000 pounds per square inch.

TABLE III.—*Physical properties of bricks produced from Iwahig clay by different processes of manufacture.*

Item.	Brick.		
	Average of Nos. 1 and 2 made at Iwahig.	No. 3.	No. 4.
Process of molding	(a)	(b)	(c)
Dimensions in centimeters	20.3×9.5×5.4	19.4×9.4×5.4	20.6×9.9×6
Weight in grams (dry)	1,807	1,821	2,153
Apparent density (weight/volume of brick)	1.70	1.82	1.80
Specific gravity	2.93	2.82	2.83
Absorption of water, per cent	20.42	16.63	15.54
Modulus of rupture:			
Transverse strength in pounds	1,010	2,250	2,460
Distance between supports in inches	6.00	6.00	6.00
$3Pl/2bd^2$	307	648	656
Crushing strength in pounds per square inch	750	1,244	1,021
Total shrinkage, per cent	----------	7.6	10.00

[a] Pressed soft mud. [b] Re-pressed stiff mud. [c] Stiff mud molded by hand.

There is not much difference between the handmade and the re-pressed bricks except in appearance; both products are much better than the brick manufactured at Iwahig.

Bricks 3 and 4 in Plate I, fig. 1, represent the product obtained by the best methods of manufacturing brick with Iwahig clay. Both were molded by hand in the condition of stiff mud, but No. 3 was re-pressed at a pressure of 3,000 pounds per square

inch after the clay had become sufficiently dry. Their physical properties are recorded in Table III, which for the purpose of ready comparison includes the corresponding average values of the Iwahig product.

The appearance and properties of brick 3 are those of the best product that can be manufactured at Iwahig, unless a suitable clay for admixture can be obtained. It is unquestionable that a brick with good color, smooth surfaces, clean sharp edges, and sufficient strength and density to meet the requirements of ordinary construction work could be obtained. For moderate demands, a brick having the above qualifications would also be good enough for face brick. To produce such bricks on a commercial scale, the clay should be ground fine enough to eliminate all danger from free lime, pugged and molded in a stiff-mud brick machine, and then re-pressed after the bricks had dried until most of the shrinkage had taken place. The same process of manufacture could be utilized to produce common floor and roofing tiles and terra cotta merely by changing the dies. The unit cost of manufacture should be no greater than it is at present.

However, for reasons which are given in the following pages, the Iwahig clay can be utilized to better advantage with the available fine-grained coral sand for the manufacture of natural (or Roman) cement. And since the natural cement can be made to serve equally well as, or better than, the brick for most purposes, the manufacture of natural cement is probably better economy than even an improved manufacture of brick.

While, from the standpoint of efficiency as a structural material, Portland cement ranks higher in order of merit than natural, or Roman cement, of which Rosendale is a type, yet for many purposes natural cement is perfectly suitable in point of strength, and for such purposes its considerably lower cost makes it more desirable than Portland cement.

NATURAL (OR ROMAN) CEMENT MANUFACTURED AT IWAHIG

A previous contribution from this laboratory[2] suggests that the present commercial and economic conditions of these Islands favor the manufacture of what may be called an artificial Roman cement. The necessity of regulating the composition is shown by Eckel.[3]

[2] Reibling, W. C., and Reyes, F. D., *This Journal, Sec. A* (1912), 7, 147.

[3] Eckel, Edwin C., Cements, Limes, and Plasters. New York City (1905), 198–199.

The work of the Bureau of Science on materials from Naga, Cebu,[4] demonstrated the possibility of manufacturing good natural cement with a cementation index as high as 2.47 from the available coralline limestones and siliceous clays. The coral sand at Iwahig requires very little grinding.

The Iwahig sand is a white, powdery material, consisting almost entirely of comminuted coral and shells. A slight residue of dark-colored grains apparently fragments of ferromagnesian minerals is obtained upon panning. The greater part of the sand which was used in the following experiments was taken from Canagaran Beach. The sand on this beach is very clean, and the deposit extends for 5 kilometers along the shore. It is estimated that there is available for each linear kilometer of beach about 15,000 cubic meters of clean sand above the low-tide level. The remainder of the sand came from the beach at Bancaobancaoan near Iwahig, where it is estimated that a quantity of 50,000 cubic meters could be obtained by dredging in shallow water. There are available, near Iwahig, at least 125,000 cubic meters of this sand. The physical and chemical characteristics of the Iwahig sand are given in Table IV.

TABLE IV.—*Characteristics of dry Iwahig coral sand.*

Ultimate chemical composition.[a]		Granularimetric analysis.			
Constituent.	Per cent.	Sieve No.	Size of mesh in mm.	Per cent retained on sieve.	Per cent passing through sieve.
Loss by ignition	44.40	20	0.92	0.10	99.90
Silica (SiO_2)	1.18				
Alumina		30	0.56	0.16	99.84
Iron oxide (R_2O_3)	1.08				
Calcium oxide (CaO)	48.00	40	0.47	0.20	99.80
Magnesia (MgO)	2.46				
Sodium oxide (Na_2O)	1.80	60	0.28	0.28	99.72
Potassium oxide (K_2O)	0.16				
Sulphur trioxide (SO_3)	0.72	100	0.15	16.28	83.72
Chlorine (Cl)	0.37				
Salt (NaCl)	0.61	200	0.07	74.44	25.56

[a] Analyzed by F. Peña, chemist, Bureau of Science.

The data in Table IV show that the sand, in its natural state, is nearly fine enough to use as ground limestone in a cement factory; that the sand contains about 86 per cent of calcium carbonate and 5 per cent of magnesium carbonate; and that

[4] Reibling, W. C., and Reyes, F. D., *This Journal, Sec. A* (1914), **9**, 127.

deleterious constituents are not present in sufficient quantities to cause any undesirable effects. In short, the sand is a very efficient calcareous raw material for the manufacture of either Roman or Portland cement. However, because the Iwahig clay is too low in silica and too high in alumina and iron oxide to produce a mixture which will meet the requirements of the Portland cement industry, the only commercially feasible plan for utilizing this sand is the manufacture of a natural cement.

The data in Table V show the composition of the four natural cement mixtures which were prepared for burning. In each instance, the sand and clay were thoroughly dried and then pulverized until 98 per cent passed through the 100-mesh sieve.

TABLE V.—*The composition of the four natural cement mixtures prepared from Iwahig clay and sand.*

Material.	Parts by weight.		Chemical constituents in per cent.					Cementation index.[a]
	Sand.	Clay.	SiO_2.	Al_2O_3.	Fe_2O_3.	CaO.	MgO.	
Iwahig clay	0	1	42.16	24.26	13.90	6.40	0.94	....
Iwahig sand	1	0	1.18	0.68	0.40	48.00	2.46	....
Mixture 1	2	1	14.84	8.54	4.90	34.13	1.95	1.47
Mixture 2	7	4	16.08	9.25	5.31	32.87	1.91	1.69
Mixture 3	7	5	19.01	10.51	6.03	30.66	1.90	2.12
Mixture 4	12	5	13.23	7.61	4.37	35.76	2.01	1.24

[a] $\frac{2.8 \times \%SiO_2 + 1.1 \times Al_2O_3 + 0.7 \times Fe_2O_3}{\%CaO + 1.4 \times \%MgO}$

These mixtures were each pugged with water to the consistency of stiff mud, molded into 9-inch bricks, and when dry burned at a temperature of about 1,000°C. in an experimental brick kiln. The resulting clinkers disintegrated more or less when exposed to the air for several days, and when moistened with water crumbled to pieces within twenty-four hours. This fact and the microscopic phenolate test described elsewhere[5] showed that considerable free lime was present. However, the free lime was not sintered, and therefore it slaked as soon as exposed to water. On the other hand, as the burned bricks contained no carbon dioxide, the raw materials had been thoroughly calcined.

Mixture 3 slaked the least and 4 the most. In all probability, better results would have been obtained by burning the mixtures

[5] White, Alfred H., *Journ. Ind. & Eng. Chem.* (1909), 1, 5; Reibling, W. C., and Reyes, F. D., *This Journal, Sec. A* (1910), 5, 367–419.

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with the highest cementation index at a low temperature and vice versa. However, there was no opportunity to make other than a rather preliminary examination of the possibilities of these raw materials in the artificial process of manufacture.

The burned bricks were soft and easy to grind. They were aërated for twenty-four hours in the laboratory, pulverized, and tested for fineness, specific gravity, soundness in steam, and setting properties. The results obtained are recorded in Table VI.

TABLE VI.—*Physical characteristics of the four artificial Roman cements.*[a]

Test.	Results.			
	No. 1.	No. 2.	No. 3.	No. 4.
Fineness:				
Per cent through the 100-mesh sieve	97.4	97.6	96.6	98.2
Per cent through the 200-mesh sieve	78.4	80.2	78.6	83.6
Specific gravity dried at 110° C	2.84	2.88	3.02	2.87
Soundness, steamed 5 hours	sound	sound	sound	sound
Time of initial set in minutes:				
Without plaster	[b]160(37)	95(37)	105(39)	heats up
With 1.0 per cent plaster	90(37)	65(36)	15(37)	20(37)
With 2.0 per cent plaster	40(37)	40(35)	15(34)	25(36)
With 2.5 per cent plaster	25(35)	25(34)	5(34)	35(36)

[a] Tested according to the 1912 United States Specification for Portland cement.

[b] The figures in parenthesis give the percentage of water required for a paste of normal consistency.

Standard specifications do not require that natural cements pass the accelerated tests for soundness, but all of these cements remained sound when subjected to the regular steaming test for Portland cements. The nonplastered, nonseasoned cements failed to harden sufficiently within twelve hours to bear the weight of the heavy Gilmore needle without showing the mark of the point. On the other hand, all of the cements gained their final set in less than ten hours, which must be considered very satisfactory for natural cements tested by the Gilmore method.[6]

The setting properties of these cements were again tested after they had aërated for eighteen hours, spread out on paper in layers about 1 centimeter thick. The results obtained are given in Table VII.

As anticipated, seasoning had the desired effect of retarding the initial set and quickening the final set, and all of the plastered cements set in a very satisfactory manner.

[6] Cf. Reibling, W. C., and Salinger, L. A., *This Journal, Sec. A* (1908), 3, 137–185.

TABLE VII.—*The setting properties of cements 1, 2, 3, and 4 aërated for eighteen hours.*

Mixture No.	Per cent plaster added.	Per cent water required for normal consistency.	Time of setting in minutes.	
			Initial.	Final set.
1	----------	35	50	600
	1.0	34	50	440
	2.0	34	45	340
	2.5	34	35	285
2	----------	35	80	600
	1.0	34	55	480
	2.0	34	50	400
	2.5	34	45	480
3	----------	35	70	500
	1.0	34	55	140
	2.0	35	50	110
	2.5	35	55	90
4	----------	40	115	600
	1.0	37	80	540
	2.0	37	70	525
	2.5	37	70	510

Unfortunately, there was not enough material left to test the hardening properties of cements 3 and 4, but the data in Table VIII show the excellent results obtained with 1, not seasoned, and 2, aërated for eighteen hours. Each strength recorded is the average of four tests; and it is worthy of mention that the differences between the average and the maximum and minimum results were remarkably small compared to the variations usually obtained with Portland cements.

TABLE VIII.—*Hardening properties of natural cements 1 and 2, containing 1 per cent of plaster.*

Test.	Results.		Requirements of specifications.[a]
	Cement 1, not seasoned.	Cement 2, aërated 18 hours.	
Tensile strength in pounds per square inch:			
Neat mortar—			
1 day in moist air	91	94	----------
1 day in moist air, 6 days in water	256	233	150
1 day in moist air, 18 days in water	296	295	(b)
1 day in moist air, 27 days in water	313	306	250
1 day in moist air, 90 days in water	370	336	(b)
1:3, Ottawa-sand mortar—			
1 day in moist air, 6 days in water	144	141	50
1 day in moist air, 18 days in water	182	194	(b)
1 day in moist air, 27 days in water	214	237	125
1 day in moist air, 90 days in water	317	242	(b)

[a] *Am. Soc. Test. Mats.* (1912). [b] Not given.

A mixture of the four cements in equal proportions aërated for eighteen hours, molded into neat briquettes, and exposed to the atmosphere in the laboratory gave the following average tensile strength in pounds per square inch:

7 days=138 pounds per square inch.
28 days=168 pounds per square inch.
154 days= 85 pounds per square inch.

The compressive strength, developed by 2-inch cubes of neat and sand mortars of the same mixtures, is given in Table IX.

TABLE IX.—*Compressive strength of cements 1, 2, 3, and 4, mixed.*

Age of 2-inch cubes.	Compressive strength in pounds per square inch.	
	Neat mortar.	1:3 Ottawa-sand mortar.
28 days in air	1,989	1,133

The strength developed by these cements far exceeds the requirements of the standard specification for natural cements, and there is little doubt but that a more thorough study would secure still better results.

Plate I, fig. 2, is a photograph of part of the Bureau of Science exhibit of calcareous-siliceous resources at the 1914 Philippine Exposition. It shows the Iwahig raw materials and the clinker, cement, steamed soundness pats, and pressed concrete bricks which they produced.

CONCLUSIONS

The Iwahig penal colony could convert its brick plant at very little extra expense into a cement factory which could produce a good grade of natural cement. The brick press at the colony would serve to mold the cement mixture and the kiln to burn the resulting bricks. It would be necessary to install only pulverizers, and as both the raw materials and the clinker require very little grinding this would not be expensive. The cost of manufacture would be much less than for the clay bricks. Neither the molding nor the burning requires great care, and it is only necessary to maintain a temperature of 1,000°C. in the kiln for from three to four hours, whereas with the clay bricks a temperature of about 1,050°C. must be maintained for twelve or more hours.

Enough work has been done to prove the feasibility of the commercial manufacture of natural cement at Iwahig and to show that the product will meet the requirements of many kinds of concrete construction work. Natural cement can be used to advantage mixed with Portland cement. A mixture containing 9 parts of natural and 1 part of Portland cement will gain strength more rapidly than natural cement and may be employed where early removal of the forms is desirable. It is probable that by further study the raw materials could be utilized to produce much better natural cements than those described in the preceding pages, and a thorough investigation should be made before a cement plant is installed.

ILLUSTRATIONS

PLATE I

FIG. 1. Bricks manufactured from Iwahig clay:
Nos. 1 and 2 manufactured at Iwahig by the soft-mud, direct-press process.
Nos. 3 and 4 manufactured at the Bureau of Science by stiff-mud processes.
Nos. 5 and 6 show effects of nodules of calcareous material in the clay.
No. 7 shows smooth surfaces obtained when nodules of calcareous materials are pulverized.
No. 8. Floor tile.

2. The raw materials and natural cement products obtained by the artificial process of manufacture.

Fig. 1. Good and bad bricks manufactured from Iwahig clay.

Fig. 2. Iwahig raw materials and the natural cement products obtained from them.

PLATE I.

THE COCONUT AND ITS PRODUCTS, WITH SPECIAL REFERENCE TO CEYLON

By David S. Pratt

(*From the Laboratory of Organic Chemistry, Bureau of Science, Manila, P. I.*)

Five plates

The cultivation of coconuts and the preparation of various commercial products from the palm form one of Ceylon's great industries that has been carefully and scientifically built up. The planters in the Philippine Islands and in the other insular possessions of the United States have much to learn from the results thus obtained, and it is hoped that the following information may be of value as well as of interest.

The facts here presented have been obtained through recent personal investigation and from various sources of undoubted authenticity. Much of the information was made available through the efforts of Mr. C. K. Moser, American consul at Colombo, Ceylon, who assisted me in every possible manner.

COCONUT CULTIVATION IN CEYLON

For the nursery, heavy round nuts are selected of such a size that from 900 to 1,200 nuts would be needed to produce a candy[1] of finished copra. The ground is carefully cleared of all roots, stones, and rubbish, and the seed nuts are planted in holes 60 centimeters deep and a like distance apart in both directions. Some sand or wood ashes are frequently mixed with the soil, or are placed in the pit prepared for the nut, to minimize the ravages of white ants. When the soil is poor, fertilizer in moderate amount is also included. The practice of using salt varies greatly, but does not appear to have any advantage, and may even be injurious to young plants.

There is a divergence of opinion regarding the best position for seed nuts, some advocating planting with the stalk end upward, others preferring a slanting or horizontal position. The latter method appears to be most popular, and is generally followed. The nursery is watered two or three times a week.

[1] One candy equals 254.5 kilograms equals 560 pounds.

When the young palms become a year old, the most healthy and vigorous are transplanted, great care being taken to prevent injury to the roots. Close planting is prevalent in the southern sections of Ceylon, and one frequently notices young palms trying to grow between rows of old trees, with the inevitable result of tall, slender trees incapable of yielding a satisfactory crop. Such conditions, of course, do not prevail in well-managed estates, where it is customary to plant 160 trees to the hectare (65 to the acre), in holes 75 centimeters by 75 centimeters and 1 meter deep. At least 30 centimeters of finely pulverized virgin soil are usually placed at the bottom of this hole.

Low-lying groves are well drained by ditches running parallel to the rows of palms, and water is not allowed to stand in the holes around individual trees.

A 3-meter circle is constantly maintained around each tree, and is kept free from grass, weeds, etc., by thorough digging. The palms are manured at least once every two years, or more frequently if the soil is very deficient. Abundant cultivation, wide planting, and careful fertilization will increase the ordinary yield of coconut palms from 50 to 200 per cent and at the same time make the palms more resistant to disease. Various firms make standing offers of free soil analyses and advice regarding the type of artificial fertilizer best suited to the estate in question. The coconut trees in Ceylon require a comparatively large amount of this treatment as there are few soils rich enough to furnish sufficient food material for abundant crops of nuts. Nitrogenous material is probably the most necessary, with phosphoric acid and lime to assist in assimilation. Excellent fertilizers are prepared in Colombo from ground fish, oil cake, nitrates, phosphates, etc.

Best Ceylon practice includes plowing the entire estate every two years, at which time the grasses, together with all small growth surrounding the cleared circular spaces, are turned under to enrich the soil. One of the most prominent features of well-kept estates is the evident care taken in removing all fallen dead leaves and rubbish. Nothing is allowed to accumulate that affords breeding places for beetles or diseases. All trees which become badly infested with beetles are felled, cut into short lengths, and burned. It has been suggested that such drastic treatment be required by law, although this has not as yet been adopted in Ceylon. The "Coconut Preservation Enactment" of the Federated Malay States, from which the Moro regulations of the Philippine Islands were derived, represents what may be

accomplished in this way. Constant vigilance in removing and killing the beetles is always necessary, but no satisfactory results can be expected unless the groves are kept clean. The infected areas of palms suffering from stem-bleeding disease, caused by *Thielaviopsis ethaceticus* Went, are completely removed with a chisel. The wounds are dried by the brief application of a burning rag soaked in kerosene, and are protected from beetles by one or more applications of hot coal tar. Bud-rot is held in check by the prompt removal of all dead or dying palms as soon as observed and by carefully burning this dangerous material. Root disease is similarly treated. These several diseases are not factors at present in Philippine groves, but careful planters must be able to recognize the symptoms and be prepared for prompt treatment should the occasion arise. The sacrifice of a few trees is a very small matter if thereby an epidemic may be averted.

The trees produce from 4 to 6 blossoms monthly, and nuts are thus maturing practically throughout the entire year. Picking is done largely by hand, and is controlled almost entirely by skilled natives who have a remarkable faculty for telling just when a nut should be taken in order to give the best product. Estate managers and others informed me that there was not a single European in Ceylon who could judge the condition of the nuts as accurately as these trained natives. Great importance is attached to this individual selection when first-class copra is desired.

There is no doubt that one factor contributing to lower the quality of Philippine copra may be found in the gross carelessness and ignorance displayed when judging the correct time for harvesting nuts. Unripe coconuts are picked in far too many instances. The harmful results of such a procedure were recognized and prevented in German Samoa by the passage of a law forbidding the picking of coconuts. All nuts must thus be allowed to drop from the trees before being used in the preparation of copra. This would appear extreme in the other direction.

The custom of cutting steps in the trunk to facilitate climbing is almost unknown to the Singhalese, even in sections where palms receive least care and attention. Nearly all trees bear one or two dried coconut leaves tied around the trunk at a height of from 3 to 4 meters. These are supposed to give the night watchman warning of thieves by the unavoidable noise made in removing or climbing over them. An interesting custom con-

cerning protection is very prevalent. This consists in painting tar in the form of snakes on the trunks, the idea being that predatory rats will be frightened away.

An average palm will produce about 40 full-grown nuts per year, although in well-kept, mature plantations this figure may be nearer 60. There are about 303,644 hectares (750,000 acres) at present devoted to this industry in Ceylon, with an annual crop estimated at 1,250 million nuts, of which 2 million are consumed daily as food and the remainder exported in one form or another (Table XIV).

The Ceylon price during 1913 for good-quality coconuts delivered at buyers' stores ranged from 40 to 56[2] pesos per thousand.

The area devoted to coconuts in the Federated Malay States in 1911 was estimated at 57,782 hectares (142,774 acres). The Chief Secretary of Government in his annual report for 1911 stated that this industry had not yet received the attention it deserves. Approximately 65,600 tons of copra were expected from the area devoted to this purpose should the entire crop of nuts be converted into this product.

The increasing imports of coconuts into the United States during the past ten years may be seen in Table I.

TABLE I.—*Value of coconuts in the shell imported yearly into the United States.*[a]

Year.	Value.	Year.	Value.
	Pesos.		*Pesos.*
1903	1,816,484	1909	2,505,188
1904	1,943,704	1910	2,591,708
1905	2,172,946	1911	3,408,210
1906	2,597,480	1912	3,898,812
1907	2,699,124	1913	3,562,754
1908	2,879,540		

[a] Compiled from Monthly Summary of Commerce and Finance of the United States, No. 12, Series of 1904–5, 1906–7, 1908–9, 1910–11, 1912–13.

COPRA

Copra is the kernel of the coconut from which the greater part of the water content has been expelled, either by the natural process of sundrying or by warming over low fires. The method employed by the native of Ceylon is very simple, and consists in merely chopping the nut in half and exposing the hemispheres,

[2] One peso Philippine currency equals 100 centavos equals 50 cents United States currency.

meat upward, on dry, sandy ground. The nuts are carefully covered at night and kept free from all dirt. The meat shrinks away from the shells after two days, and is then removed for further drying. The process is usually complete in about six days, whereupon the copra is ready for market (Plate 1, fig. 1).

Artificially dried copra is frequently inferior to the sundried product since the heat and smoke give it a darker color and wizened appearance. Fire drying requires from two to four days in the large mills and from five to seven days on native estates. The latter rate is preferable as it produces a higher grade copra. The process is essentially the same in both cases, differing merely in the rate at which it is carried out. A platform is constructed of green areca-palm (betel-nut palm) laths placed about 1 centimeter apart, forming a floor from 2 to 3 meters wide and of any desired length. This is erected about 2 meters above an earthen pit in which coconut shells are fired, after having been fitted into each other in parallel rows from two-thirds to 1 meter apart. Three or four rows of these shells are generally fired at one time, with an occasional reduction of the heat for several hours. A row of shells burns for from five to six hours, sometimes much longer. The half nuts on the platform are turned over after the second firing, and the partially dried meat is released after the third. Three more firings complete the drying. When this method is carefully carried out, only dry shells are burned, as these produce very little smoke but considerable heat. The husks are employed in the preparation of fiber, as will be shown later. The resulting copra is fairly white and clean, and since it sells for nearly top prices in the London market estate owners are content to use this method as supplementary to sundrying without employing more complex machinery. All Ceylon copra at the present time is prepared by one or both of these processes.

A very successful native drier claims he can turn out the best white copra by grill drying and even more economically than by sundrying. He fires only one row of shells at a time, and requires five days and nights of continuous heating to complete the drying. Many planters start with sundrying, and complete the preparation of their copra over grills.

The amount of copra from a given quantity of fresh nuts depends to a considerable extent upon the rate of artificial drying. Ordinarily, from 170 to 200 nuts give about 50 kilograms (110 pounds) of copra. The two extremes are encountered in comparing the output of sundried copra with that of desiccated coconut

products. The relatively low yield of the latter is well known, a decrease of 10 per cent, based on fresh kernel, not being unusual. The process of desiccating coconut will be taken up in detail under this heading; suffice here to state that drying is accomplished in less than an hour, as compared with the several days needed for drying copra.

The decrease in time required for expelling the water is, therefore, coincident with increased loss of oil, and all methods of preparing copra must represent an economical balance between these factors. It is unquestionably possible to make copra in much less time than is required by either the sundrying or grill-drying processes, but experiments made by planters in Ceylon have not impressed them with the advisability of adopting such changes. One of the most progressive coconut planters in the island constructed a drying house with brick heating flues, and produced paper-white copra in less than twenty-four hours, but discontinued the process because of the resulting high loss of oil. It is his opinion that a continuous slow current of air at from about 54° to 60° (130° to 140° F.)—the proper temperature to be determined by experiment—should complete the drying process within three days and nights, and with the least loss of oil. A rapid drying in ten hours must be attended by a considerable loss, and will require about 15 per cent more kernel to produce a given weight of copra.

Ceylon copra is graded in four qualities: "Kalpentyn," representing the best produced, followed by "estate," "Maravila" (ordinary), and "common" or "cart." Kalpentyn copra is grown nearly as far north as Jaffna, in a dry locality, and this climatic condition is generally supposed to produce an oil of lighter color. Estate copra, as its name indicates, is made from nuts grown upon estates under careful supervision. The ripe nuts are selected by competent natives, and are sundried, grill dried, or prepared by a combination of both. This preparation is superintended by a competent man, either connected with the estate or provided for the purpose by dealers who have already purchased the crop on the trees. Cart copra is a general name applied to the product purchased, piece by piece, from small producers scattered throughout the island. The dealer drives along with a bullock cart, and buys whatever is offered, frequently in lots not exceeding the production from one or two trees. The result is naturally a product that commands a lower price than the preceding.

The following rates prevailing one day in December, 1913, will give an idea of the differences in value.

TABLE II.—*Prices paid for various grades of copra.*

Grade.	Rupees per candy.	Pesos per ton.
Kalpentyn	97.25	259
Estate	96-97.25	256-259
Maravila (ordinary)	95-97	253-258
Cart	87-95	232-253

It is interesting to compare these various grades with the terms employed for Philippine copra. The best quality produced in these Islands is known as "Samar sundried." It commands good prices, but is practically all used locally for the production of oil and is consequently not included in newspaper quotations. "Cebu sundried" commands top market prices in the public quotations, followed by "F. M. M." (fair merchantable Manila). "Laguna" is frequently made from green nuts, is dried over smoky fires resulting from burning husks, and often molds before reaching the market.

The large Ceylon estates submit samples of their copra to the brokers of exporting firms, while small dealers bring their product in native *cadjan* boats from the Low Country, where it has been collected in small lots and shipped to the market. This water route is via the Kelani River and the canal passing through Negombo, Marawella, Chilaw, and Puttalam, these being the principal coconut centers of Ceylon.

The Grandpass Market, situated on the banks of the canal and a few kilometers from the fort at Colombo, is the principal market. Copra is here bought and sold every morning. Expert native brokers are employed by the exporting houses, and bid on the copra offered, generally on a commission basis. Much experience and tact is necessary in estimating the value of the copra thus offered and in purchasing as desired, for competition is very keen and margins are small. Ceylon copra is ranked as second in quality only to that of Cochin and the Malabar coast, and is quoted at about 20 pesos less per ton. However, it is generally believed by Ceylon producers that the best grades of their white oil eventually reach the consumer in large quantities as Cochin oil.

The copra destined to be exported to a foreign market for oil making is spread out in warehouses and sorted according to quality, dryness, color, etc. Each hemisphere is then chopped into three or four pieces and resacked for shipment. The work is largely done by women laborers, who receive approximately 20 centavos each per day. This handling and chopping causes a loss in weight amounting to from 0.5 to 1 per cent, and a further loss of from 3 to 5 per cent is generally allowed for shrinkage during the voyage.

Table III shows the various countries to which Ceylon copra was exported during the past three years and the amount shipped to each. See also Table XIV.

TABLE III.—*Export of Ceylon copra.*[a]

Destination.	1911	1912	1913
	Tons.	*Tons.*	*Tons.*
Germany	27,984	18,312	40,314
Russia	8,164	6,981	12,094
Denmark	550	3,950	1,258
Austria	735	1,370	2,105
Belgium	525	301	1,650
United Kingdom	375	363	75
France	775	100	
Holland	50	50	
Other countries	276		209
Total	39,434	31,427	57,705

[a] Supplements of the Ceylon Chamber of Commerce Reports.

A marked falling off of all coconut products from Ceylon in 1912 was caused by drought in the preceding years. This was also the case in other neighboring countries. Thus the exports

TABLE IV.—*Copra imported into the United States.*[a]

Year.	Amount.	Total value.	Value per ton.
	Tons.	*Pesos.*	*Pesos.*
1907	3,153	604,264	191.33
1908	6,303	962,464	152.70
1909	10,644	1,333,640	125.29
1910	9,511	1,525,120	160.35
1911	16,882	3,073,436	182.06
1912	28,831	5,620,342	194.94
1913	15,343	3,063,640	199.67

[a] Compiled from Monthly Summary of Commerce and Finance of the United States, No. 12, Series of 1908–9, 1910–11, 1912–13.

of copra from India for 1912–13 amounted to 34,350 tons valued at 8,330,991 pesos, as compared with 32,876 tons valued at 7,368,683 pesos in the previous year.

Statistics covering imports of copra into the United States show the following yearly amounts and corresponding values.

The economic loss to the Philippine Islands due entirely to unsatisfactory methods of preparing copra has been commented upon repeatedly. The actual figures are startling, as may be seen from Table V, where the monthly losses during the period from 1907 to 1911 are shown in detail.

TABLE V.—*Comparative prices per metric ton in Europe for copra from Ceylon and from the Philippine Islands.*

Month.	Ceylon.	Philippine Islands.	Difference.	Shipped Philippine Islands.	Loss to Philippine Islands.
1907					
	Pesos.	*Pesos.*	*Pesos.*	*Tons.*	*Pesos.*
January	257.90	242.00	15.90	1,850	29,415.00
February	267.00	246.00	21.00	900	18,900.00
March	270.10	248.80	21.30	1,082	23,046.60
April	255.50	239.90	15.60	4,568	71,260.80
May	245.40	229.90	15.50	600	9,300.00
June	238.00	216.20	21.80	2,500	54,500.00
July	229.90	206.20	23.70	5,250	124,435.00
August	221.70	196.20	25.50	5,035	128,435.00
September	215.60	183.50	32.10	6,610	212,181.00
October	218.70	186.10	32.60	8,500	277,100.00
November	215.30	180.30	35.00	5,886	206,000.00
December	200.70	175.70	25.00	11,750	293,750.00
Average	236.31	212.56	23.75		
Loss in 1907					1,448,323.40
1908					
January	186.14	169.22	16.92	6,000	103,520.00
February	176.40	157.82	18.58	1,250	29,750.00
March	163.62	144.78	18.84	7,500	141,600.00
April	165.46	147.44	18.02	4,000	72,080.00
May	169.10	146.86	22.24	5,000	111,200.00
June	173.36	151.46	21.90	9,000	197,100.00
July	177.12	155.98	22.14	4,350	96,318.00
August	176.06	158.60	17.46	9,750	170,235.00
September	178.34	157.82	20.52	7,250	148,770.00
October	186.38	160.86	25.52	12,750	325,380.00
November	188.86	160.58	28.28	11,000	311,080.00
December	196.12	169.54	26.64	11,848	315,630.72
Average	178.08	156.74	21.42		
Loss in 1908					2,022,663.72

TABLE V.—*Comparative prices per metric ton in Europe for copra from Ceylon and from the Philippine Islands*—Continued.

Month.	Ceylon.	Philippine Islands.	Difference.	Shipped Philippine Islands.	Loss to Philippine Islands.
1909					
	Pesoo.	*Pesos.*	*Pesos.*	*Tons.*	*Pesos.*
January	197.70	176.40	21.30	10,250	218,331.00
February	188.90	171.80	17.10	3,500	59,850.00
March	187.60	169.80	17.80	11,750	209,150.00
April	190.30	172.00	18.30	4,500	82,350.00
May	191.70	170.00	21.70	7,000	151,900.00
June	201.30	174.30	27.00	3,250	87,750.00
July	220.90	189.50	31.40	3,750	117,750.00
August	221.40	191.00	30.40	13,250	402,600.00
September	214.60	184.80	29.80	9,500	283,100.00
October	229.30	196.10	33.20	9,000	298,800.00
November	236.90	206.50	30.40	11,250	342,000.00
December	255.00	221.40	33.60	16,660	559,776.00
Average	211.30	185.30	26.00		
Loss in 1909					2,813,357.00
1910					
January	261.80	224.40	37.40	6,411	239,771.40
February	254.90	221.70	33.20	5,895	195,114.00
March	266.40	232.60	33.80	7,803	243,741.40
April	277.70	246.60	31.10	10,962	340,918.20
May	275.00	233.20	41.80	8,970	374,946.00
June	261.60	213.60	48.00	7,205	345,840.00
July	260.60	219.60	41.00	7,858	322,178.00
August	271.30	230.20	40.90	10,995	449,695.50
September	278.10	235.30	42.80	11,332	485,009.60
October	276.80	234.30	42.50	15,198	645,915.00
November	272.50	228.70	43.80	14,345	628,311.00
December	257.70	226.30	31.40	13,548	425,807.20
Average	267.86	228.87	38.97		
Loss in 1910					4,697,247.30
1911					
January	256.68	226.84	29.84	6,000	179,040.00
February	234.18	208.94	25.24	7,250	182,990.00
March	217.24	197.78	19.86	7,000	139,020.00
April	223.24	200.44	22.80	7,575	172,910.00
May	241.48	215.34	26.14	7,500	196,050.00
June	243.92	218.24	25.68	3,750	96,300.00
July	248.42	222.32	25.90	13,750	356,125.00
August	258.88	232.36	26.52	6,500	176,380.00
September	282.24	247.56	24.68	18,200	630,340.00
October	285.28	245.74	39.54	21,000	830,340.00
November	263.76	233.82	29.94	26,250	785,925.00
December	251.88	223.54	28.34	13,141	376,415.94
Average	250.60	222.74	27.04		
Loss in 1911					4,121,835.94
Loss in 5 years					15,103,427.36
Shipped in 5 years				506,327	

COCONUT OIL

Coconut oil is expressed from copra, and is largely employed in the manufacture of soap and edible fats. The latter use demands a high purity oil of light color and bland taste. Products meeting these requirements are made with difficulty from dark-colored or moldy copra, whence the demand for the better grades.

Copra is a difficult product to ship without deterioration, and is certain to become moldy with the production of free fatty acids during transit unless thoroughly dried. The only logical procedure is to extract the oil at some central point near the source of supply, thus greatly reducing the bulk of the shipment and avoiding loss due to spoilage. The operation of mills for this purpose in the Philippine Islands cannot be too strongly urged, as the economic advantage to the country would be very great. The immense amounts of coconut oil entering commerce and its financial importance may be judged from the following table showing imports to the United Kingdom during a single year.

TABLE VI.—*Coconut oil imports for 1913.*

From—	Refined.		Unrefined.	
	Amount.	Value.	Amount.	Value.
	Tons.	*Pesos.*	*Tons.*	*Pesos.*
Ceylon	216.6	85,757	8,552.4	3,183,065
India	18.3	7,740	1,294.7	517,980
Australia			4,329.7	1,595,475
France	13,517.2	5,699,167	445.1	169,983
Germany	10,948.9	4,753,010	15,339.4	5,627,193
Belgium	2,897.0	1,207,757	1,122.4	388,107
Denmark	2,410.6	1,094,839	370.9	136,877
Other countries	79.1	32,893	105.0	41,089
Total	30,087.7	12,881,163	31,559.6	11,659,769

The exports of coconut oil from India during the year 1911–12 amounted to 8,184,089 liters (2,165,103 gallons) valued at 2,626,876 pesos, of which Germany took 2,208,469 liters (584,251 gallons) and the United States 1,804,901 liters (477,487 gallons). The total export for 1912–13 was much less.

Statistics covering imports of unrefined coconut oil into the United States show the following yearly amount and corresponding values (Table VII).

Long experience in Ceylon is the basis for the general estimate that 40 full-grown coconuts will yield 3.78 liters (1 gallon)

TABLE VII.—*Coconut oil imported into the United States.*[a]

Year.	Amount.	Total value.	Value per ton.
	Tons.	*Pesos.*	*Pesos.*
1907	15,868	5,247,948	330.72
1908	18,616	6,535,170	351.05
1909	22,986	6,159,364	267.96
1910	21,583	6,682,818	309.63
1911	22,820	8,288,888	363.23
1912	20,701	7,702,558	372.08
1913	22,546	8,366,072	371.07

[a] Compiled from Monthly Summary of Commerce and Finance of the United States, No. 12, Series of 1908–9, 1910–11, 1912–13.

of oil, or approximately 1,000 nuts for 100 kilograms (220 pounds) of oil.

Comparatively little oil is expressed in Ceylon at the present time, and with the exception of a few large mills the machinery is primitive. Prices in 1912 ranged from 324.40 to 362 pesos per ton, and advanced during 1913 to 425 pesos, with little indication of falling off. Table VIII shows the amount exported to the various countries during the past three years. See also Table XIV.

TABLE VIII.—*Export of Ceylon coconut oil.*

To—	Shipped in—		
	1911	1912	1913
	Tons.	*Tons.*	*Tons.*
United States	8,696	8,640	15,918
United Kingdom	13,341	8,019	7,617
Norway and Sweden	973	1,590	2,227
Austria	843	879	725
Belgium	549	141	220
Germany	766	235	85
Holland	107	72	155
Italy	43	102	115
Russia			20
Turkey	13	14	13
India	82	61	147
Other countries	202	32	41
Total	25,615	19,785	27,283

A very brief description of the essential parts of one of the largest mills, located in the suburbs of Colombo, would include the following processes: The copra is passed through elevators to machines that cut it into small pieces, which are then ground

to a coarse bran. This is heated in large, steam-jacketed containers provided with stirrers to insure a uniform temperature. The temperature employed is very important, as it affects the quality of the resulting oil to a great degree, and it is one of the carefully guarded details of the mill. The warm mass is then run into large vertical presses, in which it is separated by perforated plates that determine the thickness of the resulting cake. Hydraulic pressure of 2 tons is gradually applied, until all except about 10 per cent of the oil is expressed. The press cakes are then ground, rolled, heated as before, and submitted to 3-ton presses that reduce the oil content to about 6 per cent. Copra yields roughly 66 per cent of oil by this method and 33 per cent of press cake, called poonac. These cakes weigh approximately 5.5 kilograms each, and are packed in burlap for shipment to the continent as cattle food or are ground with fish, phosphates, and nitrates as fertilizer for estates. Germany is the largest buyer, followed by Belgium and the United Kingdom. For yearly export, see Table XIV. The total consumption of oil cake as food for draught cattle, milch cows, and pigs is rapidly increasing. It possesses the valuable property of adding to the firmness of butter produced by cows fed upon it.

DESICCATED COCONUT

The processes employed in the manufacture of various desiccated coconut products are not so generally known as in the previous industry, and will, therefore, be discussed more in detail. The husked nuts are brought to the desiccating mills in bullock carts well covered to protect them from sun and rain. Here they are counted, and are bought at prices ranging from 52 to 56 pesos per thousand. The broken, blemished, and undersized nuts are used for making copra, while the selected ones are covered to protect them from rain and sun which would cause bursting followed by rancidity. Rain especially injures the flavor, and in case the nuts cannot be used at once they are removed to storage sheds.

The satisfactory nuts are then counted into baskets containing 50 each, which are carried to natives seated in long rows and provided with small hatchets and chopping blocks. The shells are skillfully chipped away, leaving the kernel entire (Plate I, fig. 2). These are rapidly passed to women who pare or shave off the coarse, brown outer surface. The instrument used is an ordinary carpenter's spokeshave having one end cut off. The use of special machinery for this operation was tried at

one time and abandoned as being more expensive and less efficient. The shellers and shavers are paid from 26 to 32 centavos per 1,000 nuts, good workers of either sex handling from 1,500 to 2,000 nuts per day. Children for carrying, etc., receive about 20 centavos per day.

The parings are carefully collected and spread out on cement floors to dry (Plate II, fig. 1). Women provided with rakes turn this material over from time to time until the copra thus produced is ready for the grinders and presses, where it is combined with that made from discarded nuts. The entire amount is not large, even in mills capable of turning out considerable desiccated coconut, but is a by-product well worth handling. The broken shells are used for fuel to fire the engines, and in one mill visited they were utilized as a very satisfactory source of producer gas for an internal combustion engine.[3]

Hand shelling and shaving is used for all ordinary forms of desiccated coconut, such as "granulated" and "threaded," but for certain grades, especially "chips," it is advantageous to have the kernel come to the knives in perfect form. This is accomplished by cutting the entire nuts into quarters with a circular saw, that the meat may leave the shells intact. The shaving is then done by a selected corps of women. The men at the machines receive from 32 to 40 centavos per 1,000 units.

The shaved nuts are thrown into tanks of fresh, cold water to remove all milk or particles of dirt. Three successive washings are generally given the kernels on their way to the desiccating room. This is necessary to keep the meat fresh and clean, as otherwise rancidity would injure the flavor. All opened nuts must be prepared and packed ready for shipment within twenty-four hours; if not, they must be discarded for copra. The nuts are now quartered and sliced by women workers, given a final washing, and packed in baskets for the machines. The wash water is run into tanks, where the oil is allowed to rise until it can be skimmed off. Irregularly shaped pieces of nut are sent to the "granulating" machines and pieces of proper length to the "thread" machine. Shaped portions of entire nuts go to the "chip" machine, where they are packed in special steel baskets holding perhaps half a dozen pieces. These baskets are open at both ends. A filled basket is then introduced into a machine that turns out shavings of coconut not unlike the wood shavings from a carpenter's plane.

[3] This use for shells offers a very promising source of power.

Shredded coconut is manufactured solely for the American market. It requires slightly different methods in preparing the meat and a special shredding machine consisting of a rotating disk with four sets of knives fixed in slots. The knives for making "shred" or "strip" have serrated edges, and are not set at any special angle. The same machine is used for "flake," but with knives having a chisel edge and set at a proper angle.

A shredding machine with fast and loose pulleys, together with one full set of knives for flakes and another for strip and capable of handling somewhat in excess of 50 kilograms per hour, sells for about 390 pesos. The men at these machines work by the day, and receive from 22 to 32 centavos, with 50 per cent extra for overtime. During rush season, when the mill cannot shut down, these laborers invariably refuse to work in day and night shifts, but remain at work for practically twenty-four hours at a stretch. Women workers receive slightly less wages than the men.

The grating machine consists of a spindle upon which are placed a number of circular saws. These protrude slightly through a grating into a small open cast-iron box to which is given a reciprocating motion. Nuts are pressed into the box, and come into contact with these rapidly revolving saws, while the motion of the box causes all portions of the coconut to be acted upon. A grating machine provided with fast and loose pulleys and a full set of saws is quoted at 350 pesos, requires approximately 3 horsepower for its operation, and slightly exceeds the capacity of the desiccator described in the following paragraph.

The freshly cut or "wet" coconut is carried immediately to the desiccating machines. No. 4 Brown's patent desiccator is the best for coconuts, and has been adopted generally by all Ceylon firms handling this product. Each machine has an approximate capacity of 50 kilograms of desiccated nut per hour, and sells for 1,358 pesos. Here the moist product is placed in shallow trays 5 centimeters deep, 1.2 meters square, and having perforated bottoms. The desiccator holds 5 such trays at a time, and consists of a sheet steel chamber through which a current of air heated from 82° to 93° (180° to 200° F.) is rapidly driven by fan. The air is heated as a rule by individual furnaces placed at the side of the machine just outside the desiccating room. The furnaces consume either wood or coal, and frequently coconut shells are burned, although these destroy the fire bars very rapidly unless used with wood or coal.

During the course of from thirty to sixty minutes, the moisture content is reduced to the allowable maximum of 1.5 to 2 per cent, leaving a paper-white product that crumbles readily between the fingers.

The dry coconut is now removed to mechanically operated screens and sifted into fine, medium, and coarse grades, differing merely in relative size but with no distinction in quality. All products of this class are made by essentially the same process and from the same nuts. Granulated, chips, thread, and shredded coconuts vary only in form according to the requirements of the various markets. The graded products are taken to the packing room, where they are spread out on zinc-topped tables to cool for from two to three hours before being placed in chests. These chests are made either from dark Ceylon redwood or a better quality of Japanese Momi wood. Tea-lead linings are made over proper-sized forms by skilled workmen who have learned to solder the easily fusible foil, an operation requiring considerable practice. Many chests are imported from Japan, both for packing desiccated coconuts and for tea. These cost from 64 to 80 centavos each at the wharf. The coconut is packed in these chests by aid of a hand press and is hermetically sealed, the net weight being about 59 kilograms per chest.

It is estimated that the "wet" coconut loses approximately 50 per cent of its weight during desiccating, and owners of Colombo mills expect an average of 150 kilograms of desiccated product per 1,000 nuts. In northern districts this figure is frequently as high as 173 kilograms. Attempts have been made in southern India to produce desiccated coconut products, but have not been successful owing to competition with Ceylon, partially because nearly twice as many Malabar nuts are required for a given output and also because of the higher cost of Indian coconuts.

It is difficult to estimate the number of laborers employed in the desiccating mills in Ceylon, but one of the largest of the four principal ones employs between 500 and 600 men, women, and children at an average wage of 28 centavos per day. These mills with this force are able to handle from 75,000 to 90,000 nuts per day.

All of the desiccated coconut is exported, the bulk of it going to the following countries in the order named: Great Britain, Germany, and the United States. The yearly export and dis-

tribution of the product may be seen from the following table, which shows the prices of the various products in the foreign markets, principally London.

TABLE IX.—*Market value in pesos per kilogram of desiccated coconuts.*

	Dec. 30, 1913.	Apr. 30, 1913.
Shredded	0.30–0.33	0.32–0.33
Chips	0.33–0.35	0.35–0.36
Threaded	0.36–0.38	0.38–0.40
Granulated	0.29–0.32	0.31–0.33

Table X shows the estimated cost in Ceylon of a plant capable of handling 90 tons of desiccated coconut per year.[4]

TABLE X.—*Estimated cost in Ceylon of a plant capable of handling 90 tons of desiccated coconuts per year.*

Buildings.	Pesos.
Nut stores (iron roof, brick walls, and floors)	2,800
Superintendent's dwelling	3,400
Office	600
Storehouses for fuel and material	2,000
Storehouse for copra and parings	2,000
Tool house and forge	680
Chopping and shaving shed (iron roof and pillars, brick floors, and trough)	2,800
Desiccating factory (iron roof and structural work, brick wall, 17 by 30 meters)	16,000
Engine room	1,400
Packing room	1,400
Copra drying kiln	1,400
Carpenter's and box maker's shed	680
Total	35,160

Machinery.	Pesos.
Engine, oil or gas, 50 B. H. P.	14,000
8 double desiccators	18,400
2 disintegrators	2,700
2 sifters	660
Plummer blocks (shafting)	2,000
Belting	500
Trolleys and rails	400
Electric light plant	2,400
Tools	300
Spare parts, etc.	2,000
Total	43,360

[4] Quoted from Rutherford, Planters' Note Book. Colombo, Ceylon (1913).

These figures are included not because of great accuracy or exact application to conditions here, but rather to supply all available information regarding a little-understood industry suitable for the Philippine Islands.

The following table shows the extent and destination of this product:

TABLE XI.—*Export of Ceylon desiccated coconut.*

To—	Shipped in—		
	1911	1912	1913
	Tons.	*Tons.*	*Tons.*
United Kingdom	7,098	5,656	6,339
Germany	2,610	2,723	2,302
United States	2,588	2,462	3,787
Belgium	363	603	558
Holland	273	461	315
Austria	264	375	306
Spain	195	268	237
Australia	565	640	709
Canada	173	303	373
Africa	101	92	98
France	70	168	112
New Zealand	154	150	97
Other countries	98	64	93
Total	14,552	13,965	15,326

COIR FIBER

The manufacture of fiber from coconut husks is another industry well suited to the Philippine Islands, but which has never been exploited here. Its introduction would not only result in utilizing the husks as an added source of profit both to large and small planters, but would at the same time tend to eliminate the harmful practice of burning husks for copra drying. The fire from husks is smoky and much less desirable than that resulting from shells alone, as it produces dark-colored copra of inferior grade. The coir industry is profitable in Ceylon, and gives employment to many women and children, especially since it may be carried on by individual workers during spare hours as well as in a mill equipped with modern machinery. In fact, the best grade fiber is made entirely by native methods. Galle is the center of the native coir manufacture, and a trip through the surrounding country will disclose nearly every family engaged with piles of husks or partially prepared fiber. All the processes employed are simple, even where machinery is

used. The primitive methods in vogue throughout the Galle District may be taken as representative of native manufacture.

Bamboo inclosures, each of a few square meters' area, are constructed along the numerous streams, esteros, and the sea. The husks are thrown into these pens and submerged by adding lengths of palm trunk or other suitable material (Plate II, fig. 2). The action of the water is allowed to soften the husks for about six days, and is generally considered to give a more desirable fiber where a mingling of fresh and salt water acts upon the material. The softened husk is placed upon a block and thoroughly beaten, either with a stone or a short stick, thus causing a separation of the fiber. The outer surface is then stripped off as valueless, and the fiber is shaken free from fine bits of husk, woody pulp, etc. It is then hackled with a coarse wooden comb and dried. Two classes of fiber result, the coarse "bristle fiber" averaging 30 centimeters in length and the finer "mattress fiber." The latter is spun into what is known as "coir yarn" in strands about 40 millimeters thick and 17 meters long. The spinning is done by women who rapidly twist the fiber between the thumb and palm of the hand, building up two strands, which are then twisted together. Women employed in this way claim to earn from 0.60 to 1.20 pesos per day, but no definite information is available as they work at irregular times under no supervision.

Husks are purchased by the bullock-cart load at fiber mills for about 16 centavos per hundred, although it is possible in some localities to procure them without other cost than cart hire (Plate III, fig. 1). They are then quartered and placed to soak. Better type mills conduct the softening process in large tanks with iron rails to keep the husks submerged. Others utilize swampy ground with soaking pits.

The soft husks are removed after five days and carried to a machine known as a "breaker" that crushes them in preparation for the "drums" (Plate IV, fig. 1). These are in pairs, a coarse machine for the first treatment and a finer one for the second. They are circular iron wheels 1 meter in diameter, and revolve at high speed. The 35-centimeter rim is studded with spikes that tear out the woody portion of the husks held against them, leaving separate the long coarse fibers (Plate III, fig. 2). Torn and broken fiber that falls from the spikes is fanned, spread in the sun to dry, subsequently cleaned, and finally baled as mattress fiber (Plate IV, fig. 2). The long, coarse fibers are washed, cleaned, and dried. They are then

further hackled by women, who comb them through long rows of steel spikes, set upright at short intervals along a table top. The fibers are now bunched in hanks approximating 30 centimeters in length with a diameter of from 4 to 6 centimeters. These are then baled for shipment by hydraulic presses or receive a preliminary bleaching with sulphur fumes. The bales are sewn up in jute for better protection, and weigh from 100 to 125 kilograms each. This fiber is used in the manufacture of brushes etc. The mattress fiber is spun into coir yarn from which an excellent rope is made. It is also made into various mats and coarse cloth. For the latter purpose, it is frequently dyed brilliant reds, greens, and purples with aniline colors. The weaving is done with primitive looms built on lines identical with those used in weaving Philippine native cloth. There are two principal grades of Ceylon coir yarn known as "Kogalla" and "Colombo," which are further subdivided into from 15 to 24 standards differing slightly in thickness, color, twist, etc.

Mattress fiber and yarn for export are stoutly bound with iron bands in bales weighing from 100 to 125 kilograms. The demand for coir yarn exceeds the present supply, and the price is steadily rising. Table XII shows the market prices of the various products.

TABLE XII.—*Market price of fiber products in pesos per ton.*

Product.	December, 1912.	November, 1913.
Bristle No. 1	168.80	107-167
Bristle No. 2	119.60	
Mattress No. 1	31.60	26- 33
Mattress No. 2	22.80	
Coir yarn Nos. 1 to 6, Kogalla	143.20-214.40	154-220
Coir yarn Nos. 1 to 6, Colombo	129.60-194.80	140-206

Exporters' usual prices range from 146 to 290 pesos per ton (cost, insurance, freight), New York.

It has been estimated that 1,000 coconut husks will produce from 30 to 35 kilograms of bristle fiber besides about 140 kilograms of mattress fiber and yarn. Practically the entire export of these products is to the United Kingdom and Germany. The yearly imports of coir yarn into the United States and the value of this product may be judged from Table XIII. See also Table XIV.

TABLE XIII.—*Coir yarn imported into the United States.*[a]

Year.	Amount.	Total value.	Value per ton.
	Tons.	*Pesos.*	*Pesos.*
1907	1,980	333,994	168.68
1908	3,322	640,050	192.67
1909	3,091	550,250	178.01
1910	2,721	409,898	150.64
1911	3,436	618,136	179.90
1912	4,051	827,908	204.37
1913	3,269	624,098	190.91

[a] Compiled from Monthly Summary of Commerce and Finance of the United States, No. 12, Series of 1908-9, 1910-11, 1912-13.

The various types of fiber product may be judged from Plate V.

Table XIV shows the amounts of the various coconut products exported from Ceylon during the past ten years.

TABLE XIV.—*Yearly export of coconut products from Ceylon.*

Year.	Oil.	Copra.	Desiccated coconut.	Poonac.	Coconuts.	Coir yarn.	Bristle and mattress fiber.
	Tons.	*Tons.*	*Tons.*	*Tons.*	*Thousand.*	*Tons.*	*Tons.*
1904	24,981	35,715	8,356	12,290	16,957	4,536	6,340
1905	29,741	19,665	9,276	13,535	18,047	5,653	7,546
1906	26,954	22,556	9,023	12,957	16,013	5,150	8,246
1907	23,900	19,258	10,403	11,410	13,813	5,311	9,239
1908	33,506	38,440	12,237	15,232	21,188	5,658	8,713
1909	29,074	38,601	11,598	12,685	18,135	5,130	7,404
1910	30,819	38,345	12,143	15,479	16,114	5,439	8,820
1911	25,612	39,440	14,555	10,699	15,589	5,776	9,759
1912	19,787	31,427	13,971	8,451	15,983	5,193	11,728
1913	27,288	57,706	15,328	11,998	16,858	5,762	12,852

OTHER PRODUCTS

The most important of the remaining products is undoubtedly the fermented drink arrack, made on a large scale from sap excreted by the flowing stem. Many palms are devoted to this purpose, being leased by native manufacturers. The process is too well known to merit further discussion.

A new use has been found for surplus shells that gives promise of future development. The dry shells are either burned to charcoal in pits, or are destructively distilled in iron chambers. The latter method produces a pyroligneous liquor that finds

application in coagulating rubber latex. The charcoal from shells is excellent, and enjoys a growing demand. It would seem as if this offers opportunities for profit in the Philippines.

Table XV, showing freight rates from Colombo to New York and to London, is included for comparison with rates from Manila.

TABLE XV.—*Freight rates from Colombo in pesos per ton (November 8, 1913).*

Product.	To—	
	New York.	London.
Coconut oil	17.50	13.75
Coconut, desiccated in cases	18.75	13.75
Coconuts, in bags	16.25	11.25
Coir, in pressed bales	16.25	11.25
Coir yarn and fiber, in bundles or coils	9.25	7.50
Coir yarn and fiber, in crewed bales	16.25	11.25
Coir bristle fiber, in pressed bales	16.25	11.25
Copra, in bags	17.50	15.00

Coconut butter is rapidly becoming important, and a brief outline of the method employed in its manufacture should be of interest. The following process is extensively utilized in Bohemia, where the output has increased during the past six years from 40 tons a day to nearly 300 tons, and the price has correspondingly advanced from 40 to 60 pesos per 100 kilograms.

The oil is extracted from copra in the usual manner with oil presses. It contains soap fats, and frequently has an unpleasant odor. Powdered chalk is added to the crude oil, and settles to the bottom after absorbing the soap fat. The free oil is passed through 4 or 5 filters, and is run into a steam-heated tank, where the temperature is raised to about 270°C. until the oil is clear and begins to bubble. It is then passed through an automatic weighing machine and subsequently run into molds, cooled, and packed.

The combined soap fats are freed from chalk by treatment with sulphuric acid, and are sold to manufacturers of soap. The addition of sesame oil to render the butter more pliant is a common practice. Coco butter keeps well even in warm weather, either raw or refined, and closely resembles oleomargarine.

ILLUSTRATIONS

PLATE I

(Photographs by author)

FIG. 1. Sundrying copra in Ceylon.
2. Removing outer shells from coconuts in preparation for desiccating mills.

PLATE II

(Photographs by author)

FIG. 1. Sundrying refuse from desiccating mills. This is pressed for oil.
2. Soaking husks to soften them before separating the fiber.

PLATE III

(Photographs by author)

FIG. 1. Coconut husks at a small fiber mill in Negombo, Ceylon.
2. Rear of mill, showing exit of fiber and heaped-up fiber after fanning.

PLATE IV

(Photographs by author)

FIG. 1. Carrying soaked coconut husks to fiber mill.
2. Carrying separated fiber from above husks to hackling table.

PLATE V

(Photograph by Martin)

Trade name.	Pesos per ton.
No. 1. Medium roping	150
No. 2. Stout roping yarn	140
No. 3. Ceylon yarn	220
No. 4. Comming weaving yarn	200
No. 5. Fine weaving yarn	230
No. 6. Best red allapas	290
No. 7. Best augrezi	300
No. 8. Coir yarn	240
No. 9. Ceylon fiber, low grade	90
No. 10. Ceylon fiber, high grade	170
No. 11. Bundle of bristle fiber	......
No. 12. Coir fiber mat	......

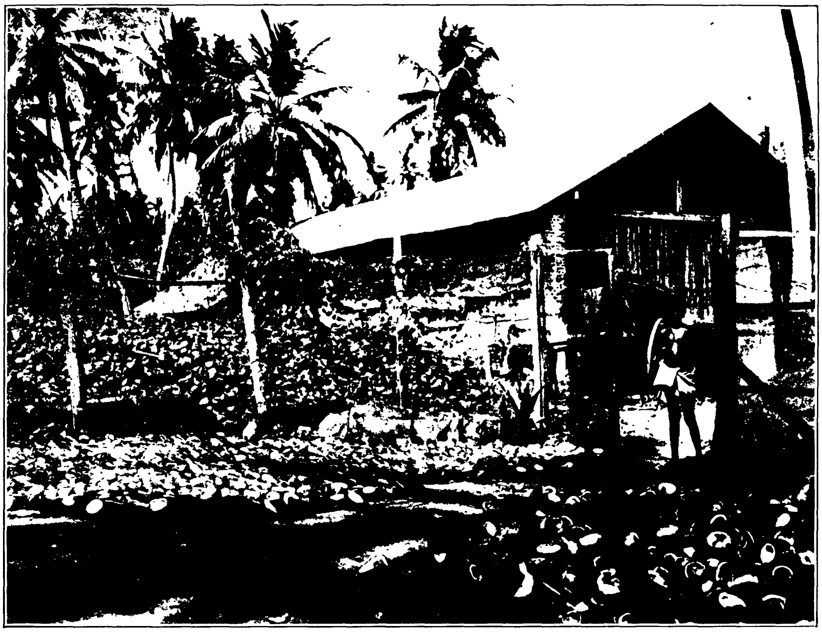

Fig. 1. Sundrying copra in Ceylon.

Fig. 2. Removing coconut shells preparatory to desiccating.

PLATE I.

Fig. 1. Drying refuse from desiccating mills for copra.

Fig. 2. Soaking coconut husks before separating the fiber.

PLATE II.

Fig. 1. Coconut husks at a small fiber mill in Negombo, Ceylon.

Fig. 2. Rear of mill, showing exit of fiber and heaped-up fiber after fanning.

PLATE III.

Fig. 1. Carrying soaked coconut husks to fiber mill.

Fig. 2. Carrying separated fiber to hackling table.

PLATE IV.

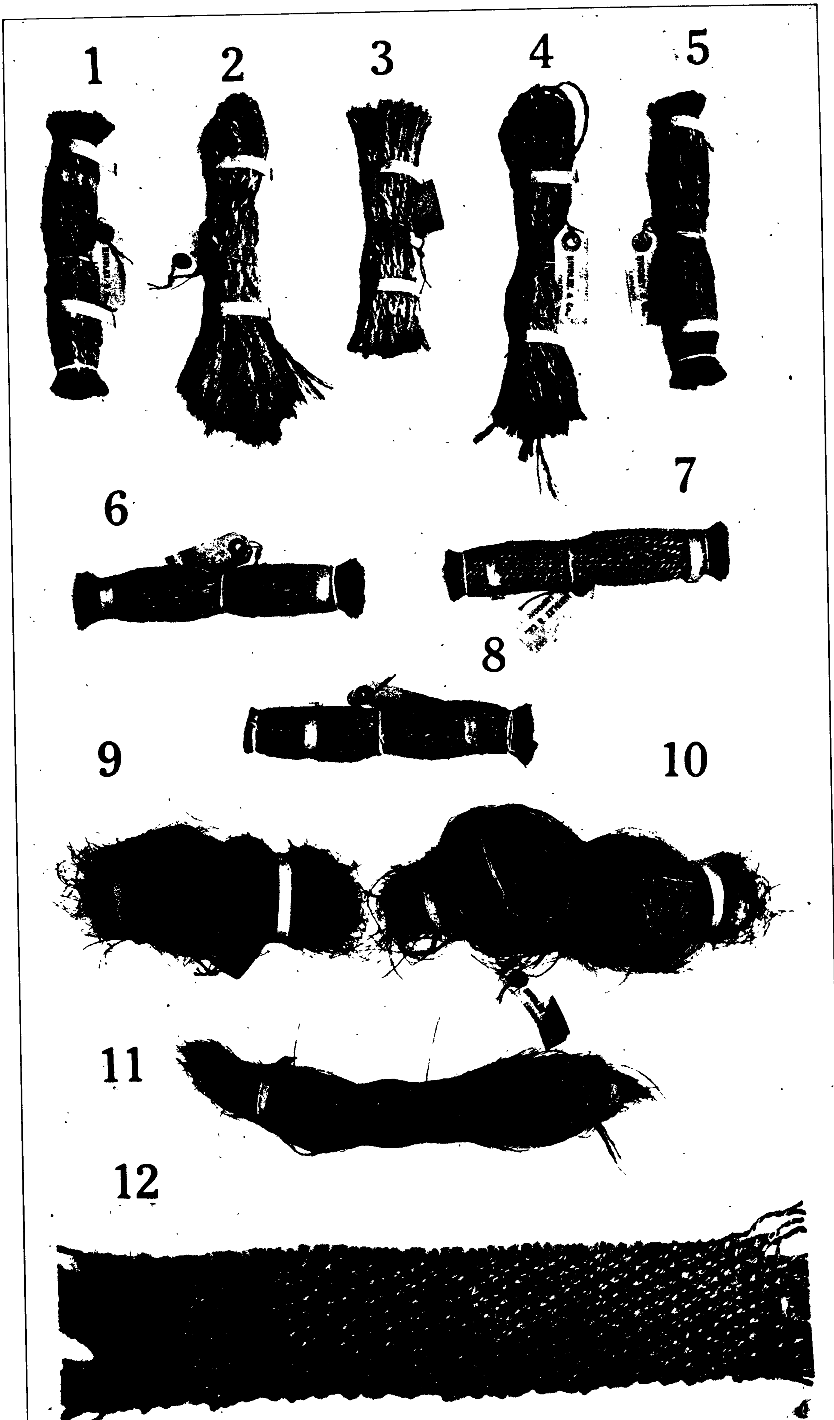

PLATE V. VARIOUS PRODUCTS MADE FROM COCONUT FIBER. SAMPLES 1 TO 10, INCLUSIVE, WERE SUBMITTED BY HINDLEY & COMPANY, LONDON.

THE PHILIPPINE

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THE IRON ORES OF BULACAN PROVINCE, P. I.

By F. A. DALBURG and WALLACE E. PRATT

(From the Division of Mines, Bureau of Science, Manila, P. I.)

One map, 6 plates, and 6 text figures

CONTENTS

INTRODUCTION

GENERAL STATEMENT

The iron-ore deposits in the Eastern Cordillera of Luzon were discovered early in the seventeenth century, and it is a matter of record that attempts at mining and smelting iron ore were made as early as 1664, although it is not clear whether the reference is to the deposits in Bulacan Province or to the similar deposits in Rizal Province which adjoins Bulacan on the south.

The importance of iron ore to industrial progress has been recognized alike by the Spanish and American Governments in the Philippines. The Spanish Inspección de Minas spent considerable effort in attempts to establish an industry in iron mining and smelting, while the first geologic reconnaissance by the Bureau of Mines [1] of the American Government was devoted to the iron-ore deposits near Angat, Bulacan Province. However, there was demand for more detailed information than it had been possible to obtain in the early reconnaissance, and after the edition of the Bureau of Mines report, which was published in 1903, became exhausted the work recorded in this paper was planned.

SCOPE OF THE PRESENT PAPER AND SOURCES OF INFORMATION

The principal field work for this report was performed by F. A. Dalburg and Wallace E. Pratt. On December 6, 1911, Mr. Dalburg, chief of the party, and Feliciano Nable went into the district. On January 4, 1912, Mr. Pratt joined the party, and Warren D. Smith, formerly chief of the division of mines, Bureau of Science, spent a week in the field at about this time reviewing the progress of the work. Field work was suspended at the end

[1] McCaskey, Hiram Dryer, *Bull. P. I. Min. Bur.* (1903), 3.

of January, but was resumed again on February 19 by Mr. Dalburg and Mr. Pratt who remained in the field until the middle of March. In the preparation of the manuscript for publication it became apparent that additional geologic data which would necessitate further field work were required. The stress of routine activity in the division of mines delayed the accomplishment of this additional work until December, 1913, before which time Mr. Dalburg had severed his connection with the Bureau of Science. Consequently, the supplementary field work which required about one month's time devolved upon Mr. Pratt. Mr. Pratt is also responsible for the preparation of the manuscript which is based upon the notes of Mr. Dalburg, Mr. Nable, and himself.

This investigation was undertaken with the idea of aiding the established Filipino iron-smelting industry and of determining the possibilities of commercial exploitation on a larger scale. The plan included (1) a study of the geology of the ore deposits in its bearing upon a determination of the quantity and quality of the ore available; (2) a study of the factors which would affect the mining and smelting of the ore, such as transportation, fuels, fluxes, power, market, etc.; and (3) a study of the native smelting process with a view to its possible improvement and expansion. The smelting process, however, was found to afford so large a field for investigation that it will be taken up in a separate paper to be published later.

The detailed work involved was rendered very difficult by reason of the situation of the ore deposits in a heavily wooded, mountainous, and almost impassable region, together with the lack of an accurate map and the entire absence of subsurface mining operations. The funds available did not permit the making of a complete accurate map of the district, and it was therefore necessary to rely upon the existing maps supplemented by compass traverses.[2]

In the absence of underground development the estimates of the tonnage in the ore reserves are of necessity based upon the observed areas of the outcrops and geologic nature of the deposits. A magnetic survey was attempted in the vicinity of

[2] The map accompanying this report was compiled from original compass surveys made in connection with this study, surveys by the Spanish Inspección de Minas, by the Engineer Corps of the United States Army, and by McCaskey. McCaskey's map is very good over parts of the area, but a glaring defect is the inexplicable distortion by which the Camaching District is located north of the town of Sibul; its true position is far to the south of this town.

each outcrop, but these surveys yielded no data which could be used in quantitative determinations.

McCaskey's work, already referred to, is the most important publication on the Bulacan iron ores and iron mining. McCaskey mapped the region and described in detail the smelting process, but was unable to devote much time to the geology of the ore deposits. A report by Maurice Goodman[3] contains accurate cost and production data for the mining industry, together with a design for an improved blast furnace. Warren D. Smith[4] has published brief notes on the geology of the region, and has ventured an opinion on the genesis of the ore. The other published references are brief general descriptions, the value of which is principally historical, or reports of the former annual mine inspections of the Spanish Government.

SUMMARY OF PRINCIPAL RESULTS OBTAINED

The iron ores of Bulacan are situated in the edge of the Eastern Cordillera of Luzon in an inaccessible and undeveloped region; the ore bodies are not continuous, but are found at intervals over a distance of about 15 kilometers. They occur at the base of the Miocene sedimentary rocks in the overlap of these beds on the older complex of deep-seated and effusive igneous rocks of the cordillera. Intrusive rocks in the form of dikes are found in proximity to the ore deposits, and are probably genetically related to the ores. The largest ore body is at Camaching in the northern part of the region, but other deposits which may be of commercial importance are situated at Hizon, Santol, and Montamorong.

The ores consist of magnetite and hematite in intimate mixture; quartz is the most abundant gangue mineral, but pyrite is also common. Magnetite, hematite, and pyrite occur as primary minerals in quartz; quartz and pyrite also occur as secondary minerals. The ore occurs in veins and as replacements, the latter class of ores being more important. The largest deposit is in sedimentary rocks with which it conforms in strike and dip; it replaces limestone and clastic sediments. Some of the ore bodies are probably in igneous rocks. The walls of the ore bodies are uniformly composed of a soft dark green rock made up of complex silicate minerals which is comparable with the "skarn" characteristic of some of the Scandinavian iron-ore deposits.

[3] *6th Annual Rep. P. I. Min. Bur.* (1905), 48–56.
[4] *Min. Resources P. I. for 1909* (1910), 32; *ibid. for 1910* (1911), 57.

The ores which are mined at present average more than 60 per cent of metallic iron, but the bulk of the ore reserves is probably somewhat lower in iron. Phosphorus is below the Bessemer limit in most of the ores. Sulphur is not generally present in prohibitive amount. Siliceous ores, which are not utilized at present, occur in considerable proportion.

The origin of the ores is ascribed to contact phenomena attendant upon the intrusion of the dike rocks, although the replacement ores are not confined to immediate contacts and there is little evidence of extreme high-temperature mineralization. The findings do not support the theory which had been suggested previously that the ores are surficial deposits resulting from the alteration of pyrite and other iron-bearing minerals and the concentration of the resulting iron by surface waters; consequently, the economically important conclusions based on this theory that the ore will become more pyritiferous with depth and will fail entirely within a short distance from the surface do not apply. On the other hand, it is reasonable to assume that the ore will persist unchanged to a depth commensurate with the other dimensions of the outcrops.

Although an unqualified statement of tonnage cannot be made with development at its present stage, it is reasonably certain that more than one million tons of ore are available. The correctness of this estimate could be ascertained by simple exploration work at no great cost. It is probable that several times this quantity of ore is available.

The ores are at present exploited in a small way by Filipinos who produce cast-iron implements, such as plowshares and plowpoints, directly from the ore by a primitive smelting process. The beginnings of the smelting industry date back as far as 1664, and although the process has borrowed methods from both the Spanish and the Chinese it is unique in many respects. Like most primitive smelting operations, the process is not efficient although it is profitable under existing conditions. The ores are not self fluxing as has been stated, but as the process is conducted a suitable slag is automatically formed from parts of the furnace walls. Quartzose ores which are at present discarded ought to be utilized, and a plan by which they could be utilized is suggested.

The Bulacan ores might be exploited on a larger scale by the electric smelting of iron and steel. The fundamental requirements, such as suitable ore, water for hydroelectric power, charcoal, and fluxes for reduction, etc., are met in the conditions

which obtain. The situation of the ores in a difficultly accessible region makes them less readily available than other known ores in the Philippines.

GEOLOGY

SITUATION OF THE ORE DEPOSITS

The Bulacan iron ores occur along a north-south line which lies near the western border of the Eastern Cordillera of Luzon (fig. 1). Discontinuous exposures are found over a total length

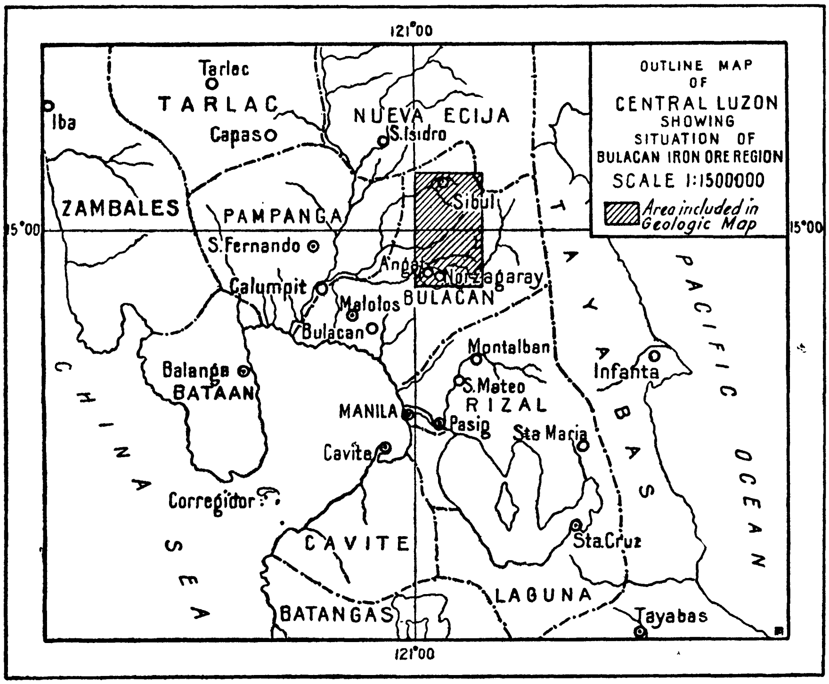


FIG. 1. Outline map of central Luzon, showing situation of Bulacan iron-ore mining region with respect to Manila.

of 15 kilometers, the southernmost exposure being about 8 kilometers northeast of the town of Angat, Bulacan. Further east, near the axis of the cordillera, are several minor deposits, and at Santa Inez and Bosoboso in Rizal Province, some 45 kilometers to the south-southeast, are other iron ore deposits similar in general character to those near Angat.[5] Only the Bulacan ores are to be discussed in this paper.

The town of Angat is almost due north of Manila, and is distant some 60 kilometers by the main routes of travel. It is situated

[5] Adams, G. I., *This Journal, Sec. A* (1910), 5, 106.

on Angat River about 17 kilometers upstream from Baliuag where the Manila-Cabanatuan branch line of the Manila Railroad crosses the river. There is a fair road between Angat and Baliuag and a first-class road from Baliuag to Manila. From Angat it is possible to reach Manila more directly by going to Bocaue over a very poor road and thence to Manila by train. It is likewise possible to ship freight from Manila to the vicinity of Baliuag by shallow-water transportation across Manila Bay and up Angat River.

From Angat to the ore deposits transportation is difficult. Only foot trails are in use at present, and on account of the rugged topography the construction of better roads would be expensive. It is more feasible to approach the northernmost ore deposit, Camaching, by going north to Sibul and then coming back southeast up to the valley of Balaong River to the ore deposit. By this route Camaching is 147 kilometers from Manila, while a direct route via Angat is only 80 kilometers in length.

PHYSIOGRAPHY

The area shown on the general geologic map includes a part of the low-lying, flat Central Plain of Luzon and the foothills of the Eastern Cordillera up to the crest of the first or westernmost range. Although the highest elevations are only about 1,000 meters, the drainage is deeply incised between sharp ridges and peaks with precipitous slopes. The greater part of the mountainous area including the vicinity of the ore deposits lies at elevations between 200 and 500 meters.

At this latitude (about 15° N.), the Eastern Cordillera is made up of three parallel ranges trending in a general north-south direction. Angat River flowing southward in its upper portion separates the western and central ranges to a point south of the ore deposits where it breaks through the western range and flows westward across the Central Plain. The upper part of Angat River receives very little water from eastward-flowing tributaries, and does not control the water courses in the vicinity of the ore deposits. Instead, drainage from territory immediately adjacent to it on the west, including the region of the southern ore deposits, escapes to the west through Bayabas River, a subsidiary and roughly parallel stream, which reaches the edge of the Central Plain before it finally joins the larger stream. Balaong River, rising in the vicinity of Camaching very close to the upper Angat farther north, flows northwest out of the area, while between Balaong and Bayabas Rivers several streams flow westward from the iron-ore region to the Central Plain.

The influence of the structure upon the development of the topography may be detected in the general north-south alignment of ridges and water courses parallel to the axes of intrusions and folds in the cordillera and to the general strike of the sedimentary strata. The western dip of the beds in much of the area of stratified rocks is reflected in long gentle slopes on the western sides of ridges and steeper eastern slopes. A belt of limestone running across the region in a north-south direction forms a conspicuous ridge or line of hills through which the drainage passes either in deep gorges or in underground courses (caves).

The Central Plain supports a large population, and is given over largely to rice cultivation. The foothill country is partly under cultivation, but the larger part of it is covered with scrub timber. The cordillera is practically uninhabited, and is heavily forested. Near the smelting centers which are located at the ore deposits, the forest has been cut away for charcoal, and the cut-over areas have become an almost impassable jungle of second-growth timber, bamboo, and rattan.

GENERAL GEOLOGIC RELATIONS

The Eastern Cordillera as a whole is a complex of Pre-Miocene, igneous rocks, folded sedimentary rocks, most of which are of Miocene age, and extrusive rocks of varying age. The Central Plain is made up of younger flat-lying sedimentary rocks. In that part of the western range of the cordillera shown on the geologic map the sedimentaries lie upon the western flank, deep-seated igneous rocks occupy a central position, and effusives and intrusives in a general way make up the eastern slope.

The most conspicuous holocrystalline rock is a granite which is exposed in an elongated area with its longer axis extending in a north-south direction. The strata in the sedimentary formations strike parallel to this line, and dip generally to the west. They overlap directly upon both the granite and upon older effusives. Fringing the granite are numerous small areas of intrusive rocks from which dikes extend into the granite, the sedimentaries, and the older effusives; these intrusives are usually of porphyritic or of fine-grained holocrystalline textures. East of the granite, the rocks at the surface are usually altered effusives, in part fragmental. In some of the deeper cañons holocrystalline rocks of related types are exposed.

The stratigraphic sequence is indicated in fig. 2, and the general structure is shown in the generalized east-west cross sections through the region (fig. 3). Overlapping upon a base-

ment of older igneous, including both surface and deep-seated types of undetermined age, Miocene sediments were laid down. The base of this series and the rocks upon which it lies are cut by dikes or small intrusions. In the upper part of the series andesites are found which, although fragmental, appear likewise

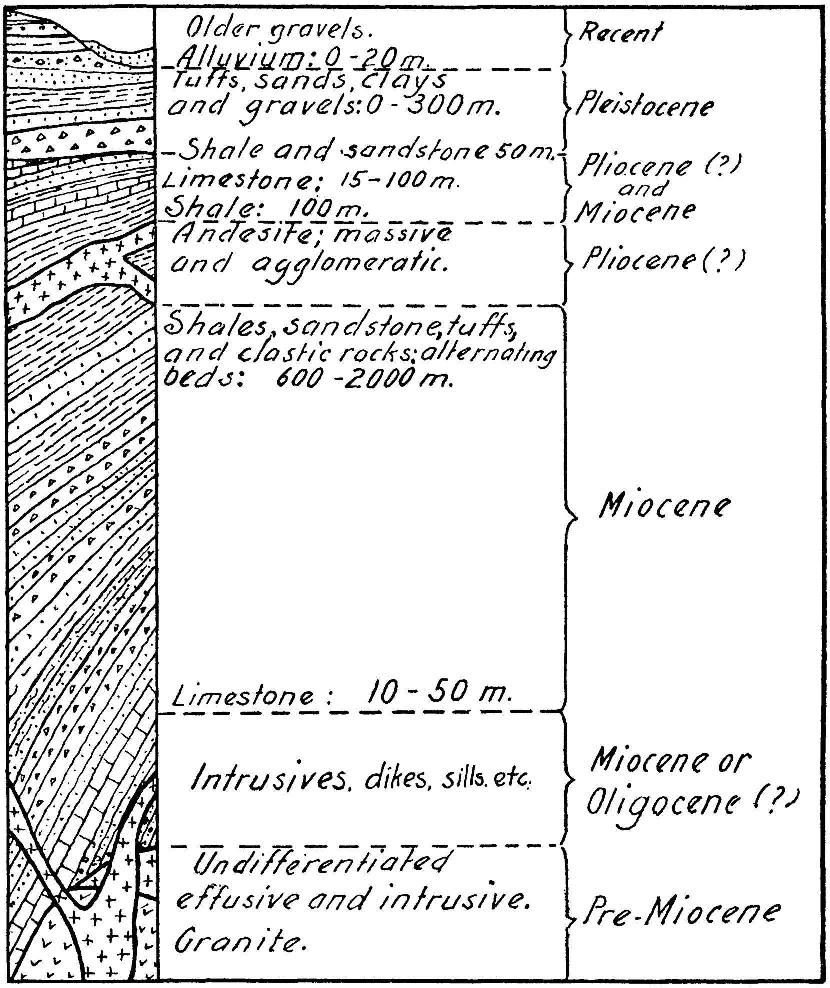


FIG. 2. Stratigraphic column for the Bulacan iron-ore region.

to be intrusive, but are probably later than the intrusions in the basal beds. Overlying the Miocene beds unconformably are bedded tuffs, clays, sands, and gravels which are believed to belong to the Pleistocene, and upon these in turn are recent deposits including older gravels and modern alluvium.

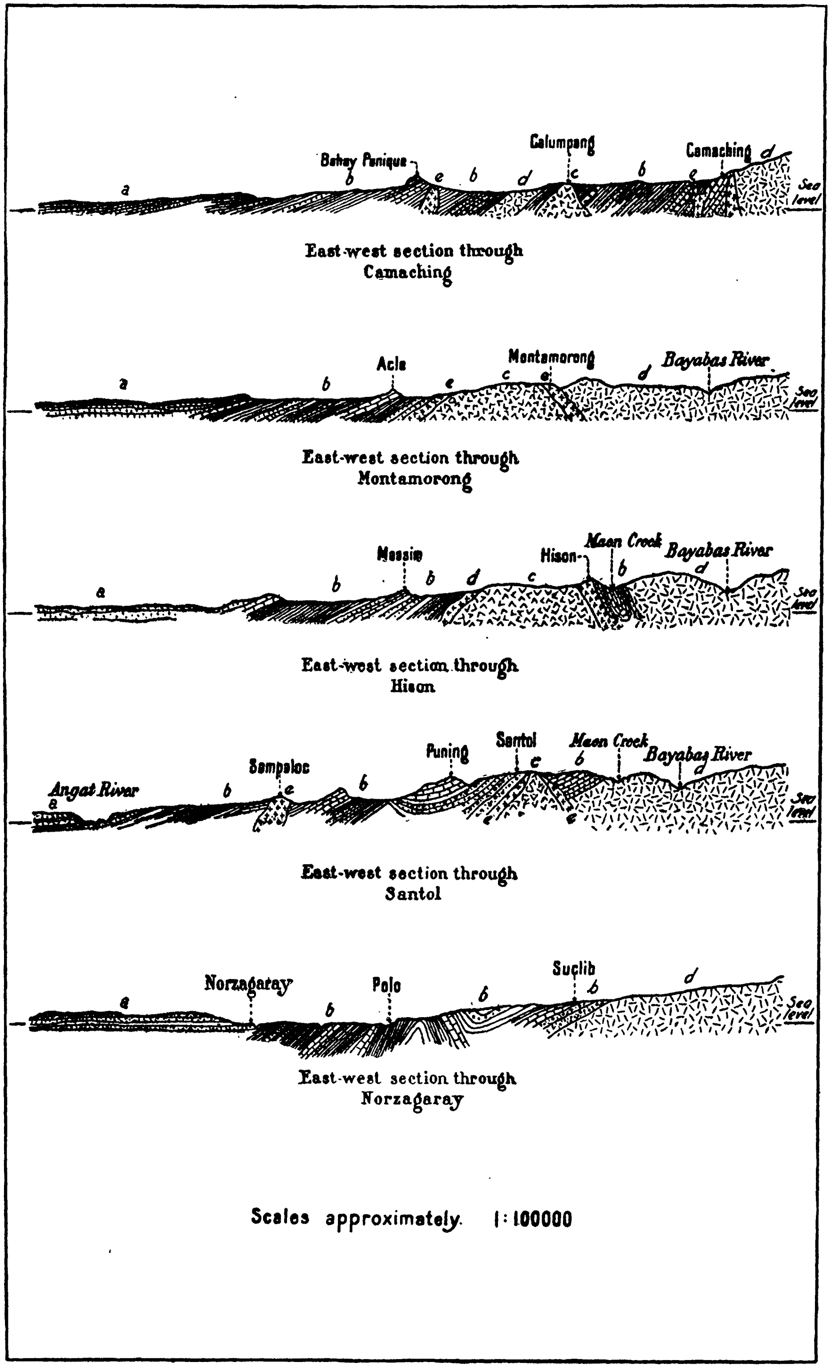


FIG. 3. Geologic sections through the iron-ore region, diagrammatic in part: (*a*) Post-Miocene sedimentaries; (*b*) Miocene sedimentaries; (*c*) granite; (*d*) effusives with intrusives; (*e*) intrusives with effusives.

SEDIMENTARY ROCKS

Post-Miocene formations.—Alluvium is developed along Angat River in the vicinity of Norzagaray and Angat, between which towns the river shifts across a wide valley floor. The town of Matictic above Norzagaray occupies an alluvial flood plain. The alluvium in this vicinity, owing to its position just at the point where the swift mountain stream debouches upon the plain and in consequence loses much of its transporting capacity, is made up largely of coarse gravel with subordinate proportions of sand and clay. The erosion of a comparatively large area of complex geologic formation in the cordillera has resulted in a wide diversity of rock types in the gravel.

The older gravels indicated in fig. 2 occur at an elevation from 25 to 35 meters above the present level of Angat River, and attain a maximum thickness of about 10 meters. They are not confined in their distribution to a former valley of this stream, but are found uniformly north and south of Angat along the eastern edge of the Central Plain. In Nueva Ecija Province to the north, these gravels have been exploited in a small way as placer-gold deposits, and in the vicinity of Angat itself fine gold can be obtained from them by washing. In contrast with their extended occurrence to north and south, the gravels do not persist over more than a few kilometers laterally. Their western boundary coincides roughly with that of the area mapped, while to the east they do not continue beyond the barrio of Sampaloc.

The gravels are probably to be looked upon as overlapping alluvial fans formed at the margin of the cordillera during earlier stages of erosion. The individual fans have been more or less commingled and spread out, probably through the lateral shifting of the streams flowing across them. There is a notably larger proportion of light-colored siliceous rocks in the older gravels than in the modern alluvium, and it may be assumed from this that at the time of their deposition erosion in the mountains was confined in its action to a horizon represented by the present ridges of altered and silicified effusives. No attempt has been made to differentiate the relatively small areas of alluvium and of older gravels from the underlying Pleistocene formation on the geologic map.

The Central Plain is built up of a series of tuffs, clays, sands, and gravels, which attains a general thickness of at least 300 meters. This series of rocks occupies the western portion of the area shown on the map, and overlaps on the Miocene beds

along the eastern edge of the Central Plain. Artesian wells in the vicinity of Angat near the edge of the plain have gone down to a depth of 150 meters without passing through these beds. At Moronco, west of Angat, the uppermost member is coarsely fragmental tuff, but at Angat the fragmental tuff has been removed and beds of fine tuff and clays are exposed at the top of the series. The artesian well records show thick beds of coarse gravel in clay, together with fine tuffs, clays, and subordinate fine clean gravel. The fine tuff and clay exposed by Angat River carry numerous pieces of carbonized wood and also numerous calcareous concretions. The strata lie nearly horizontal, but minor displacements through faulting are to be observed. Fossil leaves of species closely related to those at present living are found in the clays, and the formation is believed to be not older than Pleistocene.

Miocene formations.—The greater part of the area mapped is occupied by sedimentary rocks of late Miocene age. This formation extends across the area from north to south in a belt of varying width. The thickness in the exposed sections also appears to vary, as may be seen from an inspection of the graphic sections (fig. 3). It has not been possible to make close measurements of the thickness of the series because of the absence of continuous exposures, but it is believed that the maximum thickness is close to 2,000 meters. The beds are inclined at many places steeply toward the west, the strike varying from north 30° west south of the ore deposits to north 30° east in the northern part of the area. There are numerous local overturns or folds, but the formation as a whole is tilted away from the cordillera. There appears to have been displacement at a number of places along faults about parallel with the strike, but the study has not been sufficiently detailed to supply definite information with regard to faulting.

A thin discontinuous limestone made up of well-preserved corals marks the top of the series, and immediately below it is a sandy, brownish yellow shale. It seems probable from the results of studies of similar formations elsewhere in the Philippines that these two members are as young as the Pliocene. Underlying the shale is a much more prominent limestone which can be traced south in almost continuous exposures to the Binangonan limestone in Rizal Province. The age of the Binangonan limestone has been definitely fixed by Smith [6] as Miocene, to which

[6] *This Journal, Sec. A.* (1913), 8, 242.

therefore the limestone in question can be assigned. Corroboratory evidence as to the age of this limestone was obtained by study of a sample take from Bagum Barrio on Bayabas River, in which fragments of *Lepidocyclina* were found and identified by Smith as a Miocene species.

The Binangonan limestone is conspicuous along the margin of the Central Plain in this region. It is yellow to white in color, crystalline in texture, and massively bedded in structure with numerous vertical joints which give weathered exposures a columnar appearance. An unusually fine-grained, bedded exposure near Bagum Barrio has been exploited to some extent as lithographic stone. The maximum observed thickness, about 100 meters, is exhibited in the precipitous upper slopes of the hills southeast of Sibul.

Beneath this limestone is the principal member of the Miocene series, a succession of shales, tuff, and sandstone, which is exposed in greater thickness at Camaching than in the southern part of the field. Together with one or both of the limestones between which it occurs, this member reappears in irregular exposures to the east of the granite exposure. The strata in the upper part overlying the volcanic agglomerate are indurated and nonuniform in bedding, with small rounded pieces or tongues of andesite along the bedding planes. Fragments of chalcedony and silicified wood are common in this portion of the formation, and warm mineralized springs issue from this horizon at several places within the area mapped.

These upper shales are encountered uniformly throughout the area, but the beds below them present considerable variation. In the northern part of the region the upper shales overlie bedded andesite tuffs, flows, and clastic rocks with an aggregate thickness from 1,500 to 2,000 meters. Along Bayabas River farther south the beds next below the upper shales consist of an upper zone of fine-grained, regularly bedded, calcareous shale which is gray, brown, or red in color and a lower zone of tuff-sandstone, fine-grained clastic rocks, quartz-sandstone, and conglomerate. The whole Miocene series in the Bayabas River section is less than 1,000 meters thick. The conglomerate is at the base of the series, and is found at places immediately overlying the igneous basement of granite and older effusives. An exposure on Santol Creek reveals such a relation, and in the conglomerate are angular pieces of both the granite and the older effusives. Undoubtedly the quartz in the quartz-sandstone and conglomerate was also derived through erosion from decom-

posed exposures of the granite. The varying thickness of the column of sedimentary rocks, as exposed by erosion at different places, is due apparently to the increasingly greater overlap of the successive beds upon the older basement.

Very close to the base of the series, which from the presence of the Binangonan limestone in its upper portion has been designated as Miocene, is a subordinate thickness of white crystalline limestone or marble. This limestone was not identified in all parts of the area, and is not differentiated on the geologic map from the shale-tuff-sandstone member in the base of which it occurs. Its stratigraphic relations are most clearly developed near Camaching, where it is thoroughly metamorphosed and is interbedded with tuffs and clastic rocks near the base of the series.

The Binangonan limestone, with the underlying shales, tuffs, sandstones, and clastic rocks and the lower limestone, can be correlated stratigraphically with the coal-bearing Miocene in other parts of the Philippines, notably in Cebu. In the Cebu sedimentary column the lower limestone, which is immediately above the basal conglomerate, is rich in fossils, and in a sample collected by one of us, Smith has identified tentatively *Heterostegina margaritata* Schlumberger, which according to L. Schlumberger[7] was found by Martin in the Oligocene near Dax (France ?). It is probable, therefore, that the limestone at Camaching is Oligocene in age, although at this place it either is not fossiliferous or the fossil outlines have been lost in the crystallinity resultant upon metamorphism.

To the east of the iron-ore deposits and outside the region shown upon the geologic map are a number of small detached areas of sedimentaries, in some of which reddish slates were found apparently underlying the rocks just described. From the presence of annular tests suggestive of radiolaria in samples of these slates, Smith is inclined to correlate them with the Baruyen chert of Ilocos Norte and the Ulion slates of Panay which he considers to be probably Jurassic.

The sedimentary rocks are related to the iron ores through the occurrence of the latter, together with intrusive dikes, at the base of the Miocene series and the association of the Camaching ores with the lower limestone.

[7] Note sur un Lepidocyclina nouveau de Borneo in *Samm. d. geol. Reichsmus., Leiden* (1902), 1, 6.

IGNEOUS ROCKS

Effusive rocks.—The effusive rocks can be divided at once into an older and a younger series, the one antedating the sedimentaries and the other being probably contemporaneous with the later stages of sedimentation.

The later effusives are represented by the agglomerates and massive andesites (flows ?) in the upper part of the Miocene beds. The best exposure is found south of Sampaloc and Bagum Barrio on Bayabas River, where a small lens-shaped area is encountered, the major axis of which trends north and south. Whether the effusives at this point were spread out contemporaneously with the beds in which they occur or were forced into these beds at a later date is uncertain. The agglomerate structure, tuffaceous matrix, and other characteristics suggest purely surface rocks, but a slight metamorphism and irregularity of the overlying beds are evidences of a disturbing factor, intrusionlike in its effect, which was active subsequent to their deposition. There is no indication that the period of vulcanism marks a break in the sedimentary processes, and it is clear that the volcanic rocks came from an adjacent center of extrusion. Under such conditions confused relations would be a natural result.

The agglomerate is composed of irregular fragments of porphyritic andesite, usually less than 20 centimeters in diameter, embedded in a soft, decomposed, light-colored matrix. The formation presents no appearance of bedding, but is closely jointed. No petrographic determinations were made, but the rock is classed as an andesite from megascopic examination. The porphyritic fragments consist of small phenocrysts of plagioclase feldspar in a preponderant dark-colored groundmass which is almost glassy in many specimens. The exposures of massive-appearing rock are more like the matrix than the fragments in character.

Probably some of the rocks in the area of effusives and intrusives which lies to the east of the ore deposits are to be correlated with the later agglomerates, but such occurrences cannot be delimited without more complete data.

The older effusives are typically much altered and thoroughly impregnated with silica. The hills and ridges to the east of the ore deposits are composed very largely of rocks of this class. They are light colored, felsitic, and are usually fractured or brecciated, the cracks being stained with iron oxide. A representative older effusive from Mount Maypapa which lies just

outside the eastern edge of the central part of the area shown on the map is described by Rowley [8] as follows:

The specimen is an aphanitic rock, variously tinted gray, pink, yellow, and brown, with areas, sometimes roughly banded, which resemble feldspar crystals, but have a cherty appearance. In thin section the rock is seen to be an altered porphyry, stained with iron oxide and composed almost wholly of cryptocrystalline quartz. The outlines of the phenocrysts indicate that they were originally feldspar, which has been completely replaced by silica, cryptocrystalline to crystalline in character. The groundmass is likewise cryptocrystalline quartz. Anhedrons of magnetite in various stages of decomposition are scattered throughout the rock. Iron oxide is so abundant as to make the rock opaque in part.

A sample taken from the upper slopes of Mount Camanglao, just east of the Hison ore deposit, is classified by Rowley as a rhyolitic type composed largely of quartz and feldspar anhedrons of microcrystalline to microgranular size. Silica has replaced much of the original rock material.

Green altered felsites in the vicinity of the Hison and Constancia deposits were classed by Smith as fragmentals, probably tuffs, and Eddingfield found similar rocks from Santol to be silicified tuff.

The conspicuous feature of the older effusives is their alteration and replacement by silica. In their present condition they are essentially iron-stained quartz.

Intrusive rocks.—The numerous small exposures of fresh-appearing rocks which are encountered along the perimeter of the granite and in the base of the sedimentaries have been spoken of as dikes, and it is believed that these rocks occur chiefly as dikes, but the obscurity of geologic relations, due to the lack of clear exposures, the extensive mantle of saprolite, and the prevalence of impassable undergrowth renders it impossible to trace their contacts accurately.

There are several varieties of rocks which are classed as intrusives because of their occurrence in fresh unaltered condition in the decomposed granite and older effusives and in the sedimentaries. The most clearly dikelike exposure is encountered on Maarat Creek (a small eastward-flowing affluent of Maon Creek) just below the Santa Lutgarda ore deposits. This dike

[8] Petrographic studies of rocks collected by us were made by the men who at various times have performed the petrographic work required by the Bureau of Science. Warren D. Smith and Frank T. Eddingfield, of this Bureau, and Randall A. Rowley, of the University of the Philippines, have all contributed in this way to the present paper. In each petrographic description the name of the petrographer is mentioned.

is composed of a dense aphanitic grayish white rock, thin sections of which were examined by Rowley. He classifies the rock as an acid intrusive, a quartz porphyry with phenocrysts of quartz and less abundant feldspar. The quartz is much cracked and corroded; the feldspars are altered and clouded, and are also cracked and ragged in outline; both orthoclase and plagioclase were identified, but the orthoclase variety is predominant. The groundmass is microcrystalline, and is composed of consertal anhedrons of quartz and feldspar with traces of chlorite.

While this most clearly defined dike consists of a quartz-bearing acid rock, it is believed that the majority of the dike rocks are basic in character. They are dark in color, and are felsitic, finely porphyritic, or holocrystalline in texture. A sample of a dike of black felsite within the granite near Banco west of the Hison iron-ore deposit was examined by Smith; it was found to have an ophitic texture and to consist principally of plagioclase feldspar and hornblende with secondary epidote. Another rock occurring as a dike at the edge of the granite near the Montamorong iron-ore deposit he found to be quite similar in texture and composition. A second dike-rock from Montamorong he classified as a diabase—a holocrystalline rock whose texture is ophitic and whose essential minerals are plagioclase feldspar and pyroxene. An apparently intrusive rock at Santol was likewise identified as an ophitic diabase containing feldspar, green hornblende, and considerable magnetite. An intrusion in the base of the sedimentaries at the Tumotulo iron-ore deposit he classed as porphyritic andesite, with plagioclase feldspar, hypersthene, augite, and magnetite, while a sample taken from a small intrusive area at the western margin of the granite near Maasim River he determined as diorite—holocrystalline with plagioclase feldspar, amphibole, minor quartz, and magnetite.

Deep-seated rocks.—The only rock which is clearly of the deep-seated type in this area is the granite which occurs in the one rather extended exposure near the eastern edge of the cordillera. An area of quartz-diorite, which may be either intrusive or deep seated, occupies the upper valley of Bayabas River to the east of the area included on the map, and still farther east at the headwaters of Angat River very coarsely crystalline diorite was observed which is probably of deep-seated origin.

The granite is a somewhat decomposed, holocrystalline rock made up very largely of quartz and feldspar. It yields a quartz sand upon decomposition, and level exposures are invariably

covered with a deep mantle of coarse, sharp quartz. Bowlders and stream-floor exposures of the granite exhibit pitted surfaces, caused by the unequal resistance of the constituent minerals to weathering processes. Rowley examined petrographic sections of a sample from Calingnag Creek west of the Hison iron-ore deposit, and submitted the following notes:

The specimen is a light-colored, medium to coarse-grained holocrystalline rock which would be classed megascopically as a granite. In thin section it is seen to be composed principally of quartz and feldspar with subordinate epidote, green hornblende, titanite, and iron oxide. The fabric is consertal, unequigranular. The feldspars predominate slightly in abundance over the quartz which, although it exhibits some true crystal faces, occurs usually in irregular, apparently rounded anhedrons, or is graphically intergrown with the feldspar. The quartz contains many fluid inclusions as well as gas bubbles and dust particles. The feldspar is subhedral to anhedral, prismoid to equant; zonal structure is common, and Carlsbad and albite twinnings are to be observed. In places combinations of albite and pericline twinning produce the "grating" appearance characteristic of microcline. Some of the feldspars are considerably clouded, some show twin lamellations due to strain, and some exhibit a striated appearance suggesting crytoperthite. The cloudy feldspar with or without Carlsbad twinning appears to be orthoclase. The zonally developed feldspars and those exhibiting albite twinning are proved by their optical properties to be alkalic plagioclase; in quantity these two classes of feldspar are about equal. Titanite occurs usually as small anhedrons, but also in the well-known wedge-shaped form, and anhedral amphibole with a tendency to fibrous structure is present. The epidote also appears to be secondary, and together with the amphibole probably resulted through the decomposition of primary minerals, possibly biotite or pyroxene. The titanite, epidote, and amphibole are usually closely associated, and with them are small flakes of magnetite and hematite.

The rounded appearance of the quartz noted in the petrographic sections is much more pronounced close to the margins of the granite exposure, and is evident in hand specimens. Thin sections of the marginal rock from just below the Constancia ore body on Maon Creek, examined by Smith, showed corroded and rounded quartz phenocrysts in a fine groundmass which appeared to be fragmental or possibly effusive in character. Another sample from the north end of the granite area near Calumpang Smith found to consist principally of fragments of quartz and feldspar.

It appears that the granite has been subjected to some process by which a brecciated or disintegrated border zone has been recemented to form a rock much like the original granite in appearance, but with a clearly fragmental texture and a marked predominance of quartz over feldspar in abundance and in grain size.

ECONOMIC GEOLOGY

GENERAL CHARACTER OF THE ORES

The iron ores consist of magnetite and hematite in intimate mixture but in varying proportions. Both minerals are usually massive, although specularite is not uncommon. The surface bowlders appear to be principally hematite, but beneath the surface even in the shallow pits that have been opened magnetite is encountered. Thus the ores from Hison and Montomorong where pits are worked are practically pure magnetite as shown by chemical analysis, while the Santol ore and other ores which are obtained by breaking up bowlders contain very little magnetite. At Camaching, however, an ore high in magnetite is taken from the surface.

The predominant gangue mineral is quartz, although the ore used for smelting, which is selected so as to eliminate gangue as much as possible, contains an unusually small proportion of silica. The slightly leaner ore which constitutes the bulk of the ore reserve is typically quartzose, the quartz filling interstices in the iron minerals and cutting the ore in small secondary veins. Eddingfield, in a microscopic study of the Bulacan iron ores,[9] found quartz to be even more abundant than appears on megascopic examination. According to his results, some of the quartz crystallized simultaneously with the iron oxides, but the deposition of quartz was also renewed subsequently as is evident from the presence of the later veinlets through the ore. Eddingfield and Rowley agree that both magnetite and hematite occur as primary minerals in quartz.

Next to quartz, complex silicates are most prominent gangue minerals. They occur most abundantly in and near the walls of the deposits. These minerals appear to be alteration products of wall rocks caused by the action of the mineralizing solutions and, according to the determinations of Eddingfield, include fibrous amphibole (tremolite), pyroxene, chlorite, epidote, etc.

Pyrite occurs in the ore in varying proportions, but is usually conspicuous in or near the walls. Eddingfield and Rowley both found primary pyrite with the iron oxides in the ore, but pyrite, like the quartz, also occurs secondary along cracks in the ore. Chalcopyrite is found sparingly with the pyrite at several places.

The average specific gravity of the ores is 4.7; a metric ton of ore, therefore, occupies 0.21 cubic meter or 7.4 cubic feet. In the present practice all the ore is broken to nut size in mining. If it were desired, the hematite could be mined so as to produce

[9] *This Journal, Sec. A* (1914), **9**, 263.

practically no fines. The magnetites are so soft that a considerable proportion, perhaps 20 per cent of the ore mined, would be objectionably fine.

GENERAL CHARACTER OF THE ORE DEPOSITS

The ore deposits are revealed by the presence of bowlders of iron ore which are found most frequently in streams and on the hillsides adjacent to streams. Such masses weighing from 50 to 100 tons are common in the vicinity of the principal deposits, Hison and Camaching. Bowlders and large blocks of iron-stained quartz are also found in profusion near the ore bodies, and, as has been noted, the adjacent effusive rocks are highly silicified. In a general way, the deposits are arranged along a line which marks the base of the sedimentary series and the strike of the ore bodies at Camaching and Hison is parallel to that of adjacent sedimentary beds. The form of the deposits cannot be accurately determined because of the obscure geologic relations and the absence of development; but, as is brought out in the subsequent descriptions of individual ore deposits, the ore appears to occur both as a filling in cavities or veins and as an extensive replacement of the adjacent rocks. The inevitable alteration of the walls renders it impossible to define their original character, but here again in a general way it may be said that the ores occur in proximity to intrusive dikes and sills and are located in sedimentaries or in granite or other igneous rocks near their contact with the sedimentaries. Eddingfield concluded from a microscopic study of the ores and wall rocks that much of the altered wall rock was originally a diorite. Hematite was observed replacing limestones, coarsely fragmental rocks, and volcanic breccias; likewise small veins of magnetite in limestone (Plate III) and blocks of limestone inclosed in bodies of magnetite-hematite ore were noted.

At no place were veins or lodes with sharply defined walls of fresh rock noted. Invariably the walls are a soft, dark green rock composed of basic silicates, commonly fibrous, and carrying varying proportions of magnetite and hematite. The association of this greenish, altered wall rock with the iron ore is a matter of general observation with the Filipino miners, and is so nearly universal that they have learned to know it as *camisa de bacal* (the shirt or cloak of the iron ore). The suggestion at once arises that this rock with which the iron ore occurs may be analogous to the skarn of the Scandinavian iron-ore deposits. Skarn is defined [10] as a rock of varying composition, consisting

[10] Sjögren, Hjalmar, *Trans. Am. Inst. Eng.* (1907), 38, 766.

mostly of lime, magnesia, iron, and alumina silicates of the pyroxene, amphibole, and garnet groups, formed through an exchange between the silica of the quartz-feldspar rocks and the basic constituents of the ore formation. The wall rock in Bulacan consists principally of complex silicates of the amphibole, pyroxene, and chlorite groups. Those ore bodies which are not adjacent to the granite in Bulacan appear to have lacked the quarz-feldspar rocks which are involved in the origin ascribed to skarn, but if it be conceivable that the sources of the interchanging constituents may be reversed—that is, the silica be derived from the ore formation and the bases from the inclosing rocks—then the analogy of the Bulacan "greenstone" to skarn can be conceded. C. M. Weld,[11] in a description of

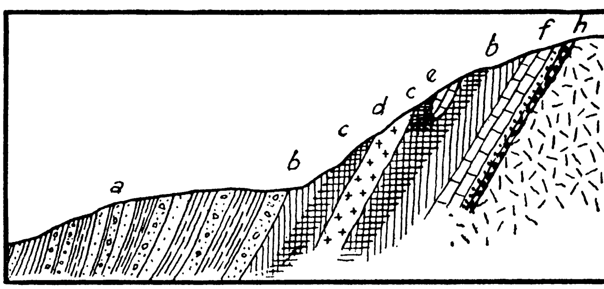


FIG. 4. Geologic section through ore body at Camaching, along an east-west line; diagrammatic in part: (*a*) Miocene shales, tuffs, and clastics; (*b*) altered wall rock; (*c*) iron ore; (*d*) intrusives; (*e*) blocks of limestone in ore; (*f*) limestone and clastics; (*h*) effusives; length of section, about 200 meters.

an iron-ore deposit near Hongkong, strikingly similar in some respects to the Bulacan ore deposits, noted the occurrence of an enveloping greenstone which he relates to skarn.

The following descriptions of the individual ore bodies will make clearer the general character of the deposits.

THE CAMACHING ORE DEPOSIT

The largest outcrop of iron ore in Bulacan Province is at Camaching near the head of Balaong River in the northern part of the district. The somewhat diagrammatic cross section in fig. 4 shows the general structure and geologic relations of the deposit. The iron ore is encountered between the usual walls of greenstone or skarn in steeply tilted beds of tuffs and fragmental rocks with a limited thickness of crystalline limestone. The altered rock in the hanging wall grades into a clastic or fragmental rock which contains a large proportion of volcanic

[11] *Bull. Am. Inst. Min. Eng.* (1914), 86, 177.

material. The limestone which occurs just below the ore and accompanying skarn lies upon a complex of effusive and intrusive rocks. Dikes and flows are found in the bedded rocks. The outcrop is exposed in the northwestern slope of a spur of Mount Silao, and can be traced over a length of 600 meters and a width of from 20 to 70 meters. It strikes north 20° east, and dips about 45° west-northwest, in strict conformity with the bedded rocks.

The ore is principally magnetite carrying quartz and pyrite which appear in each case to be present both as primary and secondary minerals. Eddingfield studied microscopic slides of the Camaching ore in which quartz and pyrite were apparently original constituents with magnetite, while the occurrence of small veins of secondary quartz and pyrite in the ore was commonly observed in the field. The ore grades into wall rocks, and the gradation stage consists of an increasingly leaner ore of magnetite with altered pyroxenes or amphiboles, pyrite, and quartz; fibrous aggregates in the green wall rock were identified as probably enstatite by Smith. Samples of the limestone replaced by red hematite were obtained; likewise veinlets of magnetite up to 15 centimeters in width cut the limestone, and "horses" or rounded blocks of limestone are found inclosed in the main body of magnetite (Plate III).

The precise relation of the intrusive rocks to the ore at Camaching was not determined. Many of the indurated fine-grained fragmental rocks are quite similar to the igneous rocks megascopically, and the two types could not be distinguished satisfactorily. A rock which is exposed with ore on both sides of it by one of the small creeks flowing across the outcrop and which exhibits the appearance of a dike was examined in thin section by Smith and classed as porphyritic andesite with phenocrysts of green hornblende and decomposed plagioclase feldspars. Another igneous rock from near the ore deposit Smith found to be holocrystalline and to contain principally pyroxene and plagioclase feldspar with some quartz. This rock might be classed as a diorite.

THE MONTAMORONG ORE DEPOSIT

The Montamorong outcrop is exposed near the eastern margin of the granite area by a small stream which is tributary to Maasim River. It is about 7 kilometers south-southwest of Camaching, and lies a little to the west of a line from Camaching to Hison. A shallow pit a meter or more in each dimension has been sunk in the outcrop. Intrusive rocks, ophitic in texture

and composed of plagioclase feldspar and pyroxene or hornblende, are prominent near the ore deposit but in undetermined relations. The general structure is shown in fig. 5.

The ore consists of soft massive magnetite with quartz and pyrite. It grades into the walls which are composed of the usual complex of silicates among which amphibole, pyroxene, epidote, and chlorite were identified by Eddingfield, together with much magnetite, quartz, and pyrite. As revealed in this pit, the ore appears to form a vein 1 to 2 meters in thickness. The outcrop can be traced over a length of 50 meters. The strike appears to be northwest and the pitch northeast at an angle of about 45°, but the presence of two strike faults with evident displacement makes the true attitude of the ore body a matter of doubt. In the hanging wall is a small parallel quartz vein carrying magnetite and pyrite. Eddingfield found by the

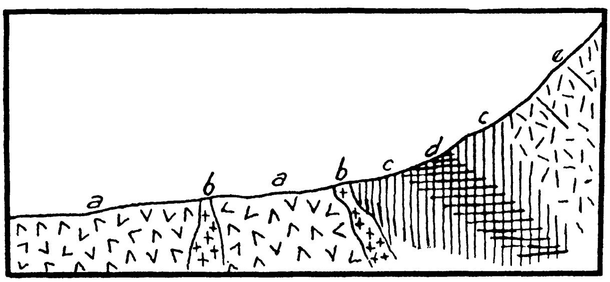


FIG. 5. Geologic section through ore body at Montamorong, along a northeast-southwest line; diagrammatic in part: (*a*) Granite; (*b*) intrusives; (*c*) altered wall rock; (*d*) iron ore; (*e*) effusives; length of section, about 100 meters.

study of thin sections that the original quartz in this vein had been shattered and recemented by quartz and magnetite.

THE HISON-SANTA LUTGARDA-CONSTANCIA ORE DEPOSIT

About 9 kilometers south-southwest of Camaching and on the line of the strike of that ore body are three adjacent outcrops of iron ore. The central and largest of these outcrops is known as Hison. About 300 meters south-southwest of Hison is the Maarat or Santa Lutgarda outcrop, and 500 meters north-northeast of Hison is a smaller outcrop called Constancia. Each outcrop is revealed by a small eastward-flowing tributary of Maon Creek. Although the ore cannot be traced in continuity from one outcrop to another, yet the exposures appear to be closely related and are probably situated on the same structural line if not actually continuous.

These outcrops lie just outside the eastern limit of the granite

area, and within a few meters farther east sedimentary rocks are found. The general relations for the Hison outcrop are shown in fig. 6. The granite in the immediate vicinity of the ore bodies exhibits the recemented border zone noted in the description of the granite, and is cut by dikes of both acidic and basic character. Some of these dikes strike parallel to the trend of the ore, that is, north 15° east, but dikes striking in various directions were noted.

A green felsite which has the appearance of a fine-grained, altered tuff occurs with the sedimentary rocks east of the outcrop. Smith examined several thin sections of this rock, and concluded that it was fragmental in character, altered, and somewhat schistose; the sections contained fragments of quartz and feldspar in a mat of minerals of the chlorite group, together with considerable magnetite. This rock grades into the usual

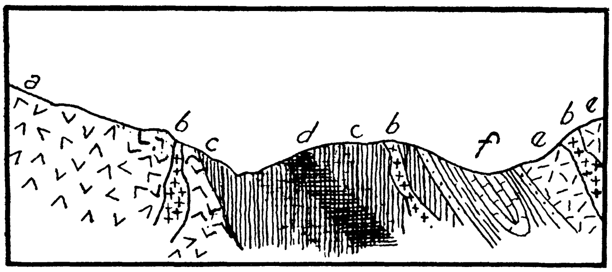


FIG. 6. Geologic section through ore body at Hison, along an east-west line; diagrammatic in part: (*a*) Granite; (*b*) intrusives; (*c*) altered wall rock; (*d*) iron ore; (*e*) effusives; (*f*) limestone, shale, and sandstone; length of section, about 200 meters.

type of wall rock at the outcrops proper. The sedimentaries consist of schistose, black, laminated shale; schistose, mottled gray limestone in beds made up of thin lenses; and a clayey sandstone-conglomerate or clastic. The strata strike north 15° east; the dip is uniformly to the east at a high angle, but the structure is evidently that of a closely folded or flattened syncline. The total thickness of the sedimentaries as exposed in Maon Creek is apparently not more than 50 meters.

At Hison, ore has been dug out of the bank of a small creek called Sapang Bacal (Iron Creek), until a face several meters in height above the bed of the stream is exposed. A wall trending north 20° east extends along the west side of the ore pit; it consists of the usual green silicate minerals with magnetite, quartz, and pyrite. The floor of the excavation over an area of about 50 square meters and one face, some 5 meters in width, are soft massive magnetite. On the surface above and south of the ore face are large, hard bowlders of hematite with magnetite. In

the stream below the outcrop to the east are numerous very large bowlders of hematite. Across the creek to the north the slope is covered with a talus of disintegrated rock and the ore does not appear. A small vein of quartz and pyrite in the wall rock is exposed a few meters to the east of the ore pit. This vein strikes north 15° east, and pitches 70° to the west.

The Santa Lutgarda outcrop is at the head of Maarat Creek. The ore appears in the form of a vein some 4 or 5 meters in width. The footwall is fairly well defined, striking north 15° east and pitching west 60°. It is an altered green rock with a fragmental appearance, either tuff or clastic. Massive hematite, specularite, magnetite, quartz, pyrite, and occasional small patches of kaolin (?) compose the ore. In thin section, Eddingfield noted hematite as a primary mineral in quartz. Maarat Creek below the outcrop carries numerous large bowlders of ore.

Constancia is a veinlike deposit which is poorly exposed and appears to be of lesser extent than Hison or Santa Lutgarda. Comparatively little float ore is found in the creek which flows across the outcrop. The ore is adjacent to the peripheral zone of fragmental granite, but is inclosed in walls of the usual green silicate minerals. The vein displays a width of a meter or more, and the walls carry much ore. The strike is north 15° east. McCaskey [12] estimated the thickness of the entire iron-bearing bed at Constancia, which was opened by pits at the time of his visit, at about 5 meters. Quartz is not as conspicuous here as elsewhere; pyrite is noticeable, especially in the altered walls. Massive magnetite is the principal vein mineral, and occurs also in the walls as grains in a mixture of finely fibrous, light-colored amphibole which Eddingfield identified as tremolite.

THE SANTOL ORE DEPOSIT

At Santol about 4 kilometers southwest of Hison, iron ore is again encountered. Numerous large bowlders of hematite are strewn over the lower slope of the steep northern wall of the valley of Santol Creek about 500 meters upstream from Puning Cave. The ore is hard, and carries considerable quartz as a filling between grains of hematite and in veinlets through the ore. The larger part of the hematite is massive, but specularite is also present. Some ore is found on the upper slopes 150 meters above the level of Santol Creek, but most of the bowlders and especially the large bowlders, some of which weigh a number

[12] *Loc. cit.*, 50.

of tons, lie near the foot of the slope. They are ranged over a distance of about 300 meters along a northeast line, which is continued farther in both directions by bowlders of iron-stained quartz. The ore bowlders lie on the surface embedded in residual clay, and no ore in place is to be seen. The rocks exposed in the stream adjacent to the bowlder ore include small areas of the granite, which is complexly distributed among altered felsitic tuffs and flows, and intrusive rocks which penetrate both granite and effusives. Limestone overlying quartz-sandstone and conglomerate is found close by, both to the east and west of the ore, and bowlders of limestone are mingled with the bowlders of ore. No replacement of limestone by iron ore, like that at Camaching, was detected at Santol; in a general way, the limestone bowlders occupy a position just above the ore bowlders on the hill slope.

It is not apparent whether the limestone east of Santol is the Binangonan limestone with which the limestone to the west of the deposit is correlated or whether it is the lower limestone. The dip of the beds is uniformly to the west in both exposures, and both limestones are much jointed; they are alike indistinctly bedded, yellow to white in color, and in large part crystalline. Faulting along the strike might have displaced the Binangonan limestone in such a manner as to make it appear at apparently different stratigraphic horizons on the two sides of the ore deposit.

In the limestone which lies to the east of the ore, a very white crystalline bed was observed, samples of which upon analysis proved to be dolomite. Dolomite is of unusual occurrence in the Philippines, and it seems probable that its occurrence here is the result of the replacement or dolomitization of original limestone. An origin related to that of the ores is suggested by the fact that most of the ores carry an unusually large content of magnesium as compared with their calcium content.

MINOR ORE DEPOSITS

At Tumotulo, 3 kilometers southwest of Santol, an insignificant quantity of ore was observed as small bowlders of hematite which occur together with similar bowlders of porphyritic andesite half way up the eastern wall of the valley of Bayabas River. The hillside on which the bowlders are found consists of shales and sandstone overlain at the top of the hill by the Binangonan limestone. The ore is massive hematite with some magnetite, quartz, and pyrite. Chemical analysis reveals the presence of 9.31 per cent of titanium oxide in this ore, whereas no other

ore analyzed contained more than a small fraction of 1 per cent of this constituent.

Smelting furnaces have been operated at Macatalinga, Mayapo, and at Tagpis 6 to 10 kilometers east of Hison, but very little ore is to be seen at any of these places. The country is made up of effusive rocks much silicified. The ore is hematite, often of the specular variety, with pyrite and quartz. It is found sparingly in small detached pieces on the surface of, or embedded in, residual clay near the summit of the divide between Bayabas and Angat Rivers.

CHEMICAL COMPOSITION OF THE IRON ORE

The ore used for smelting charges in Bulacan Province usually carries more than 60 per cent of metallic iron, and samples secured by breaking up bowlders usually carry nearly or quite as high a proportion of iron. Smelting charges as employed by the Filipino, however, represent selected ore especially in the elimination of all quartz-bearing material, and it is probable that surface bowlders are also richer in iron than a representative sample of the ore in place would be. Therefore, it may be expected that the deposits entire carry somewhat less iron than the ore which it is possible to sample at present.

The analyses in Table I show the chemical composition of samples from each of the ore bodies discussed. For convenient comparison, analysis of an ore from Hongkong and analyses of several standard iron ores have been inserted.

The analyses show that the ores smelted are fairly pure magnetites or hematite or a mixture of these two minerals; in all cases the combined water is very low. Except in the quartzose ore, alumina is high in proportion to silica as compared with the iron ores most widely smelted elsewhere. Magnesia is generally more abundant than lime. A majority of the ores are within the Bessemer limit as to phosphorus, although some exceed it. Sulphur is reasonably low in the pure ore, but is high in the replaced wall rock where it occurs as pyrite. Pyrite from Montamorong was found to contain 0.15 per cent of cobalt, and it is probably due to traces of cobalt in the pyrite generally that slags from all the furnaces show a cobalt-blue color in patches. Titanium and manganese are low with the exception of the one ore from Tumotulo which is inexplicably high in titanium. In the quartzose ores, silica increases at the expense of the iron, while in the altered wall rock it is probable that magnesium, aluminum, and lime replace the iron, although no analysis of this material was made.

TABLE I.—*Chemical composition of Bulacan and other iron ores.*

(Numbers express per cent of dry weight of ore.)

Sample No.	Moisture 100° C.	Silica (SiO_2).	Alumina (Al_2O_3).	Ferric oxide (Fe_2O_3)	Ferrous oxide (FeO)	Lime (CaO).	Magnesia (MgO).	Manganese oxide (MnO).	Titanium oxide (TiO_2).	Phosphorous pent-oxide (P_2O_5).	Sulphur (S).	Carbon dioxide (CO_2).	Total.	Iron (Fe).	Phosphorus (P).	Manganese (Mn).	Remarks.
89	0.25	5.02	4.80	66.41	20.64	0.35	0.74	0.24	0.23	0.12	0.02	1.10	100.32	62.54	0.052	0.173	Camaching ore; furnace; charge analyzed by Forrest B. Beyer, chemist, Bureau of Science.
7	------	------	------	------	------	------	------	------	------	------	------	------	------	66.00	------	------	Camaching ore; records of the Spanish Inspección de Minas.
6	0.05	4.66	3.68	62.76	27.32	0.21	1.14	0.08	trace	0.14	0.21	0.30	100.50	65.17	0.061	0.058	Hison ore; sample across 7-meter face of ore pit, analyzed by Forrest B. Beyer, Bureau of Science.
158	0.04	2.24	6.52	88.22	1.92	0.13	0.18	------	0.77	trace	------	0.01	99.99	63.17	------	------	Hison ore; analyzed by Paul Stangl, of former Mining Bureau, Manila.
8	------	43.76	2.25	40.45	13.50	nil	------	------	------	------	------	------	------	38.80	------	------	Hison ore; very quartzose sample; analyzed by T. Dar Juan, chemist, Bureau of Science.
9	------	------	------	------	------	------	------	------	------	------	------	------	------	68.47	------	------	Hison ore; records of the Spanish Inspección de Minas.
10	------	------	------	------	------	------	------	------	------	------	------	------	------	69.45	------	------	
11	------	------	------	------	------	------	------	------	------	------	------	------	------	67.48	------	------	Santa Lutgarda ore; records of the Spanish Inspección de Minas.
12	------	------	------	------	------	------	------	------	------	------	------	------	------	65.51	------	------	
159	0.37	6.72	10.10	68.36	5.14	5.04	1.51	------	trace	0.24	2.02	------	99.13	51.85	0.103	------	Constancia ore; 161 pyritic ore from roof, 162 from floor; analyzed by Paul Stangl, of former Mining Bureau, Manila.
160	0.04	2.18	15.34	48.69	32.34	trace	1.31	------	0.11	0.05	trace	trace	100.02	59.24	0.022	------	
161	3.21	14.13	12.20	57.83	4.72	1.93	0.46	------	0.51	0.14	7.81	0.03	99.76	44.16	0.061	------	
162	0.34	3.85	8.67	84.22	2.57	0.25	0.09	------	trace	trace	trace	trace	99.65	60.95	trace	------	

13														60.34			Constancia ore; records of the Spanish Inspección de Minas.
34	0.07	6.84	4.13	59.09	27.68	0.20	1.20	0.15	0.20	0.13	0.21	0.30	100.13	61.71	0.057	0.108	Montamorong ore; furnace charge; analyzed by Forrest B. Beyer, Bureau of Science.
14														67.48			Montamorong ore; records of the Spanish Inspección de Minas.
35	0.27	3.32	2.36	89.56	4.13	0.16	trace	0.05	trace	0.08	0.06	0.18	99.90	65.91	0.035	0.036	Santol ore; spalls from bowlders; analyzed by Forrest B. Beyer, Bureau of Science.
15				85.52					trace					57.72			Santol ore; furnace charge; analyzed by T. Dar Juan, Bureau of Science.
22	1.21	9.52	5.43	65.13	7.89	0.38	0.58	0.38	9.31	0.37	0.01	0.53	99.53	51.72	0.161	0.274	Tumutulo ore; furnace charge; analyzed by Forrest B. Beyer, Bureau of Science.
63	0.61	12.86	5.77	67.14	13.45	0.23	0.14	0.27	trace	0.14	0.10	0.18	100.28	57.46	0.061	0.194	Macatalinga ore; furnace charge; analyzed by Forrest B. Beyer, Bureau of Science.
67	0.25	7.29	3.99	76.15	11.66	0.31	0.28	0.40	trace	0.14	0.10	trace	100.28	62.37	0.061	0.288	Mayapo ore; furnace charge; analyzed by Forrest B. Beyer, Bureau of Science.
16		1.20		70.32	22.53	0.60	3.64	1.48		0.009	0.11		99.90	66.75	0.004		Magnetite from Hongkong, China; *Bull. Am. Inst. Min. Eng.* 3, 86, 184.
17		10.45	2.38			5.17	1.85				0.02			57.18	0.003		Magnetite from Sweden.
18	1.11	8.65	1.39			2.74	3.94				2.50			57.05	0.007		Magnetite from Cornwall, Pennsylvania.
19	12.27	6.80	2.23			0.32	0.22				0.07			58.83	0.062		Hematite, Mesabi Range, Minnesota.

GENESIS OF THE ORES

The Bulacan iron ores have a sufficient number of features in common to lead to the belief that they are related in origin, although local conditions have undoubtedly been effective in modifying the character of the individual deposits. Concerning Macatalinga, Mayapo, and Tagpis, information is insufficient to justify further statement. The titaniferous character of the Tumotulo ore sets it apart from the others, perhaps, because of the frequently observed association of titanium with a distinct class of magnetites ascribed to the action of magmatic segregation. For Tumotulo, also, the lack of information prevents more than this generalization.

Among the features which are significant as to the origin of the other and more important ores may be noted the intimate and general association of the ore minerals, magnetite and hematite, with quartz; the occurrence of ore in sedimentary rocks, as at Camaching, and the conformity of such ore bodies with the sedimentary rocks in strike and dip; the evident replacement of sedimentary rocks, especially limestone and breccia, by ore and the presence of veins carrying the ore minerals, as, for example, the small quartz veins adjacent to and parallel with the main ore bodies at Montamorong and Hison; the presence and character of the altered wall rock with the ore; and the presence of original pyrite with magnetite in the ore.

With these features in mind, it will scarcely be suggested that the ores are original beds deposited as sediments or as bog ores, nor can they be explained as the result solely of concentration or metamorphism of ferruginous beds or bog ores unless a separate origin be assigned to the small quartz veins. In this connection it should be remembered that not all the ore bodies are certainly within sedimentary rocks. Moreover, there is no evidence of regional metamorphism which is usually involved in the change of original limonite beds to magnetite and hematite; schistose rocks are not of general occurrence, and the granite which is believed to be older than the ores shows no trace of gneissic structure.

A theory advanced by Adams to explain the occurrence of iron ore at Santa Inez, Rizal Province, may be quoted here as equally applicable to the Bulacan deposits since the Santa Inez ores have features in common with those of Bulacan, namely, they consist of magnetite and hematite as ore minerals, with quartz, pyrite, and chalcopyrite, and they occur at or near the contact of igneous rocks (andesites) with sedimentaries, including

clastics and crystalline limestone. Bowlders of iron ore, in which magnetite occurred in limestone as a replacement or a vein just as it does at Camaching, were noted by one of us in Lenatin River below the Santa Inez deposit.

Adams [13] says:

* * * Bowlders of iron ore, some of which are from 2 to 3 meters in diameter are encountered about one hour's walk [from Santa Inez] up the river [Lenatin] in the bed of the stream. The mountain to the west of the river was evidently the source of these masses. The lower slope of the mountain was ascended along the bed of a stream which empties into the river just above the bowlders. The country rock exposed by erosion is an andesite containing numerous small specks of pyrite, and in some places bunches of pyrite were found in sheer zones. The larger masses of pyrite were partially altered to hematite. In places there is a small amount of chalcopyrite present and the alteration has given rise to a coating of blue and green copper carbonates. The copper ores have been prospected lately but have not been found in encouraging quantities. On the wall of the ravine, a face of rock was seen which showed a considerable amount of iron ore, coating and replacing the country rock. This has somewhat the appearance of a dyke running up the mountain, although there is no proof that it is, since the dense vegetation obscures the formation excepting in the walls and bed of the ravine. Near the top of the hill there is an outcrop of iron ore. The summit of the hill is capped by a heavy bed of limestone, such as is frequently met with in the eastern cordillera. In descending, exposures of a metamorphosed fine-grained clastic rock were seen in the bed of the ravine to the south of the one which was followed in ascending.

This rock contains specks of pyrite, but no bowlders of hematite were seen. A simple and sufficient explanation of the origin of the iron ore is that it has been derived from the pyrite which is found disseminated in the country rock and occurring as masses in the sheer zones. It is probable that the mineralization is a result of contact phenomena resulting from the intrusion of the andesite in the sedimentary formation.

According to this idea the iron oxides which are hematite and magnetite (Adams noted the occurrence of hematite only) formed through the oxidation of pyrite, which in turn is the product of contact metamorphism.

Smith [14] has proposed a similar origin for the Bulacan ores:

I wish here to record the result of my own very limited observations in addition to the remarks by Mr. McCaskey regarding the occurrence of the ore. The ore is found in the massive crystalline rocks of this region, which are in the main dioritic and andesitic. The iron ores, hematite, magnetite, etc., are alterations of these crystalline rocks in place. They are not sedimentary deposits, and therefore any regular strikes and dips, such as occur in sedimentaries, would not be found. The iron deposits, as far as I was able to make out, have absolutely no connection with the later sedimentaries. The diorite is very rich in ferromagnesian minerals, with an unusual amount

[13] *This Journal, Sec. A* (1910), **5**, 106.
[14] *Min. Resources P. I. for 1909* (1910), 32.

of iron pyrites and chalcopyrite which have gradually yielded their iron to the percolating ground water traveling along fractures. The present deposits in my opinion represent merely a segregation of iron oxide resulting from decomposition of the above-mentioned minerals.

And again, later, Smith and Fanning [15] state:

From our examination of the Bulacan deposits we can say that they are very irregular and occur with igneous rocks of the Eastern Cordillera as local enrichments from the alteration of chalcopyrite and other iron bearing minerals of that formation. The rich pockets which we examined near Angat, and from which the natives mine their ore, are located along fractures in the formation.

The observations recorded in this paper do not support a theory of origin through superficial alteration of pyrite or other iron-bearing minerals and rocks. The direct product of such alteration would apparently be limonite and possibly hematite rather than magnetite and hematite. Moreover, microscopic study of thin sections of Bulacan ores by both Eddingfield and Rowley indicates that magnetite and hematite occur as original minerals in quartz and that the associated pyrite is partly of contemporaneous deposition with the magnetite and partly of later deposition; in either case, the pyrite is generally unaltered.

F. Rinne has suggested an origin for the magnetic iron ore at Bato-balani, near Mambulao, Camarines, which could be applied plausibly to the Bulacan ores. The Bato-balani deposit has been studied by one of us; it contains hematite and pyrite as well as the more abundant magnetite, and was found to show a close similarity to the Bulacan ores, as will appear from the following translation from Rinne:[16]

* * * The mountain (a hill near Bato-balani) on its summit and its slopes over a length of 400 meters and breadth of 200 meters fairly bristled with countless large and small bowlders of magnetic iron ore. In the bed of a small stream on the side of the mountain the ore stood out in bowlders and rounded blocks; in the surrounding hemp clearing, dark, bare, frequently jagged and porous blocks protruded from the ground everywhere, and in the jungle one could distinguish the same blocks in great number in the ground. Here and there in the mottled laterite (in which the bowlders are embedded) the structure of the original rock could be distinguished. * * * Apparently the weathered rocks are to be traced to a dioritic "Eruptivgestein," of which several fairly fresh pieces were found between the ore rocks in the hemp field. * * * It might be thought that the magnetite masses here are a segregation from an igneous rock, probably from the diorite found between the ore masses. It is surprising, however, in explaining the magnetite as a magmatic segregation that nowhere was the contact between the diorite and the ore to be seen. The ore masses

[15] *Ibid. for 1910* (1911), 59.
[16] *Zeitschr. f. prak. Geol.* (1902), 10, 117.

were encountered everywhere without any adhering or inclosed pieces of diorite. This circumstance indicates strongly that the once existing rock with which the present ore blocks were associated was comparatively easily destroyed so that the ore, freed through weathering, is now nowhere to be found in continuity with them. In this connection the occurrence of a dark-colored limestone of which several pieces were found at a place on the same slope is interesting. It is possible that the ore masses were enveloped in this easily destroyed limestone. It appears to me very plausible that the magnetite blocks at Bato-balani were formed from contact phenomena between diorite and the limestone which is still found in traces over the former surface of the igneous rock. * * * One could suppose that the ore formed in the limestone under the influence of the solutions and gases coming from the cooling diorite magma. I did not observe other contact minerals, such as garnet, at this place, but in complete accordance with this theory is the occurrence of nests of yellowish white, needlelike quartz which are found sparingly in the magnetite. In places the ore particles build a sort of frame or skeleton, the spaces of which are filled with quartz. * * * The igneous rock that occurs with the magnetic iron ore is an augite-bearing hornblende-diorite. It has a speckled appearance, resulting from the arrangement of white to gray plagioclase and the scattered, rounded, or elongated grains of greenish black hornblende which dot the abundant groundmass.

It is concluded that the Bulacan iron ores are similarly the result of contact phenomena caused by intrusions. The intrusive rocks are identified with some hesitation as imperfectly defined dikes, the occurrence of which has been noted. Weld,[17] in his study of very similar deposits near Hongkong, found that the Hongkong granite was the rock whose intrusion into older sediments had caused the deposition of magnetite-hematite ores. It is not impossible that the Philippine granites, of which the granite in Bulacan is representative, are to be correlated with the Hongkong granite, but the directly resulting suggestion that the granite in Bulacan is the intrusive rock involved in the genesis of the ore deposits there is refuted by the clearly established priority in age of the granite over the sedimentaries which are affected by the intrusion.

For contact deposits, however, the Bulacan ores occur in notably large part as a replacement of the intruded rocks, limestone, and other sedimentaries; they are not confined to a narrow contact zone. In minor occurrences the ore has also filled fissures which are not on the immediate contact. Some of the more common contact-metamorphic minerals, such as garnet and wollastonite, were not identified in the Bulacan ores in spite of the fact that they were especially sought. The Camaching limestone

[17] *Lot. cit.*

at the border of the magnetite veins in it contains no minerals other than calcite.

On the other hand, some of the characteristics of the ores that have been recorded are strongly significant of contact metamorphic deposits. The association of contemporaneous magnetite and pyrite, for instance, according to the widely quoted statement of Waldemar Lindgren,[18] is the one unique feature of such deposits.

It is probable that the intrusions which are involved in the formation of the Bulacan ores cooled at no great distance from the surface; the fine-grained or porphyritic texture of all the intrusives observed would support such an idea, and it appears that the overlying sedimentary rocks, in the vicinity of the ore bodies, were never very thick in their overlap on the older rocks. If this supposition is correct, the phenomena of mineralization characteristic of deeply buried contacts would have been modified by the proximity of the surface and the absence of certain contact features so explained. Typical thermal effects from the actual contact of molten rock are subordinate in Bulacan to the more widespread effect of the solutions associated with the cooling magma. Whether the solutions were juvenile waters expelled from the magma or were heated meteoric waters circulating along contacts with the intrusions and along openings formed by the cooling and contraction of the intrusions is undetermined.

If the genesis which has been outlined in this paper for the Bulacan ores is correct, there is reason to believe that the deposits will continue in depth in proportion to their outcrop dimensions. The suggested manner of origin has a further economic bearing in that it involves no necessary increase in the proportion of pyrite in the ore with increasing depth, such as would be expected if the ores had resulted from surface alteration of iron-bearing minerals.

QUANTITY OF ORE AVAILABLE

In the absence of all development work it is not possible to estimate closely the ore reserves. In an attempt to arrive at some idea of the extent of the ore bodies beneath the surface, a magnetic survey was made at each deposit. This method failed to yield reliable information because of the deflections of the horizontal and vertical needles caused by the large bowlders of iron ore scattered over the surface in the vicinity of each ore body. Horizontal deflections of as much as 17° and corresponding in-

[18] *Trans. Am. Inst. Eng.* (1901), 31, 227.

creases in the dip of the dip needle were often obtained near outcrops, but quite without regularity, so that when plotted up according to approved methods they yielded no intelligible data. At distances of from 30 to 50 meters from the outcrops the deflection of the horizontal needle is almost normal or, more accurately, it is uniformly about 3° east, while the normal deflection in the Philippines is about 1° east. If the results of the magnetic survey alone are considered, the conclusion to be drawn is that large bodies of hematite or magnetite do not exist in the region. But if the other data presented herewith be considered, it appears that the quantity of ore is large enough to be of economic importance.

If the ores originated in the manner suggested by this geologic study, it is probable that they persist for a reasonable distance below the surface, since the dip or pitch dimension of a replacement or vein deposit which has been formed under magmatic influences, as these ores probably have, would presumably be of the same order of magnitude as the strike dimension of the same deposit. To assume that such a proportion exists in estimating ore reserves, however, would not be justified without more evidence than is available for the Bulacan ores. On the other hand, the vertical extent of the ore bodies in the present case ought surely to be as great as their least horizontal dimension, that is, their width, and in order to obtain some basis of estimation it will be assumed that such is the case.

Judging solely by the extent of the outcrops, it appears that the Camaching ore body contains a much larger tonnage than all the other deposits. The outcrop at Camaching is 600 meters long, and measured widths varied from 20 to 70 meters. The average specific gravity of the ore was determined as 4.7; taking 20 meters for the average width of the deposit over the length of the outcrop and assuming that the ore will continue in depth a distance equal to its least surface dimension, there results from calculation something over 1,100,000 tons as the estimated ore reserve at Camaching.

In view of the conservative figure used for the average width and for the extent of the ore below the surface, it appears that the tonnage obtained represents the minimum quantity of ore available rather than the probable size of the ore body; that is to say, there is present at least this quantity of ore.

Employing similarly conservative figures for the other ore bodies, there results a combined total of about 100,000 tons of ore. Indeed, only at Hison and Santa Lutgarda can one be definitely

assured that there is more ore present than the few thousand tons contained in the bowlders.

The only estimate which can reasonably be made, therefore, places the total reserves in the Bulacan ore deposits at 1,200,000 metric tons; even this figure involves an assumption as to the depth to which the ore persists. Yet, if the dip dimension of the Camaching ore body is at all comparable with its strike dimension, there is from five to ten times this quantity of ore present in this deposit alone.[19]

In view of the possible size of the ore bodies in Bulacan, there is justification for sufficient exploration work to determine something of the extent of the ores beneath the surface. It should not be particularly expensive nor difficult to carry out such exploration in the vicinities of the larger outcrops. Hand-operated core drills, it is believed, would afford the most convenient and satisfactory means of obtaining the data required for preliminary estimates.

THE MINING AND SMELTING INDUSTRY

HISTORY

The first authentic mention of iron mining in the Philippines is contained in a report[20] dated July 16, 1664, from Governor-General Salcedo to the Spanish crown. In this letter the governor-general states that he had brought out from Spain at his own expense an engineer to develop an iron mine, that 600 arrobas[21] (of iron) had already been obtained, and that he was continuing the work. This statement refers to the iron ore near Santa Inez or, possibly, near Bosoboso in Rizal Province.

Viana, a former royal fiscal, spoke[22] of the same locality on February 10, 1765, and stated that the iron mines were then in charge of Juan Solana and Francisco Casañas, that they had established furnaces, coalpits (charcoal pits ?), and forges, and had mined large quantities of iron ore. Soon after this date, one

[19] Dr. James F. Kemp, quoting McCaskey, submitted to the 11th International Geological Congress a rough estimate of from 500,000 to 800,000 tons for the ore reserves in the deposits near Angat, including, apparently, only Montamorong and the Hison-Santa Lutgarda-Constancia deposits. Iron Ore Resources of the World. Stockholm (1910), 983.

[20] MS. in Archivo general de Indios. Sevilla, folio II, 481–483. Title quoted by Blair and Robertson, The Philippine Islands, 1493–1898. Cleveland, Arthur H. Clark Company (1903–1908).

[21] 1 arroba=11.502 kilograms.

[22] MS. copy in the possession of Edward E. Ayer, Chicago. Title quoted by Blair and Robertson, The Philippine Islands, 1493–1898 (1903–1908).

Francisco Salgado secured a concession [23] to work the same mines upon the basis of an annual royalty of 20,500 gold reales and the guarantee of an output of at least 125 tons of iron each year. He secured from Mexico an engineer named José Bustos, but the enterprise failed after having obtained 2,000 piculs [24] of iron which were sold for the equivalent of 4,000 pesos.

There is a further reference to these mines in a record of their sale in 1781 to Maria Isabel Carreaga for 10,400 pesos, and when in 1798 Conde Aviles petitioned for certain iron mines on Sapa Nagaray Vivit, sitio Modete, Morong, his petition was opposed by a certain Carreaga who claimed to have the right to them through this sale.

The record of the exploitation of the Bulacan ores dates from 1781 when Juan Belli, chaplain of the Royal Armada, was entrusted with the working of iron mines near Angat. The chaplain was only the director of the work, however, and Lorenzo Lopez de Buycochea was given actual possession, on July 18, 1781, of a concession called San Felix de Valois, situated on Pinugayan Creek, which name is at present applied to the small stream at the Santa Lutgarda deposit. The limits of the property are stated as all territory within a radius of one league around the foundry, but the actual mine was only 180 varas [25] long by 2 varas wide. At this time a foundry was situated on Maasim River, and ore was evidently taken from the Santol deposit. In 1784 Buycochea sold his mine to Felix de la Rosa for 11,000 pesos.

On June 6, 1805, Juan Escalante y Lazo sought title to a mine on Santor and Viga Creeks (the present Santol deposit), and on July 4, 1806, obtained possession of a claim 400 brazas [26] square. The two sons of this man, Juan and Vicente, acquired a mine in 1816 on Tuyo Creek which was probably their father's old property, since Tuyo (dry) is another name for the upper part of Santol Creek. There is no subsequent reference to the Santol deposit in the Spanish records. It is held to-day by two Americans, Messrs. Chas. Wilson and A. G. Rose, who have two mining claims on the outcrop.

The Hison property was granted to Santiago Hison on April 25, 1816. This claim was demarcated as a circular area, having a radius of 200 varas with an outcrop on Bacal Creek as a center.

[23] Memorias historicas y estadisticas. Arenas (1850), Chap. 9.

[24] 1 picul=62.262 kilograms.

[25] 1 vara=0.836 meter.

[26] 1 braza=1.672 meters.

On January 22, 1850, José Fernando, grandson of Hison, sought title to a mine on Maon Creek, which from its description is evidently the original Hison grant. The later concession was also granted, but appears to have been surveyed 100 brazas long by 50 brazas wide. It is owned and worked to-day by the direct descendants of Hison, and constitutes the Hison mining claim.

According to McCaskey, a Chinese ironmaster, Ongsayco, who had worked in the Bulacan smelters for over thirty years, solicited 2 claims on March 21, 1873. Through faults of omission and protests by other claimants, no concession was ever obtained. Again on September 9, 1873, Quiterio Anchuelo Rodriguez sought possession of 4 claims to be known as Santa Lutgarda. Although there is no record of the issuance of title to this concession, the Spanish engineers apparently recognized it as valid judging from the records of the official visits of 1887 and 1893.

The Constancia claim of two pertenencias was regularly solicited by Francisca Talag on February 22, 1879, but the petition was opposed by Hilario Fernando on the ground that this was the same claim that had been granted to his ancestor Santiago Hison. After various legal formalities it was shown that the property solicited was separate and distinct from the Hison claim. The act of demarcation was performed on June 23, 1880, and on August 13 of the same year title was granted to Francisca Talag. There is an unofficial record that this claim was sold on July 27, 1901, to Pedro Otayco for 200 pesos.

The Montamorong deposit was solicited on November 21, 1892, by Francisco Sanchez. Demarcation was performed by Abella y Casariego, the mining inspector, on April 16, 1893, and title issued June 9 of the same year. Sanchez later sold his property to Chas. Wilson, an American.

The first reference to the Camaching ore deposit is dated October 15, 1816, when José Ycaza petitioned for a mining claim called Santisima Trinidad, situated at Ylasag, which, it appears, is the place now known as Camaching. Possession was granted on December 4, 1816, but nothing more was heard about this mine until about the year 1830 when Domingo Rojas and José Basco formed a company for the smelting of iron and the manufacture of steel and decided upon Camaching as the most favorable site for exploitation. Machinery was imported from Europe and elaborate plans were made, but the transportation of the machinery from Manila to Camaching proved so difficult that it was left scattered along the road and the attempt failed. On January 22, 1853, Joaquin Melchor de la Concha petitioned

for title to a mine located at Camaching, and in 1856 Enrique and Francisco de la Concha also sought title to mines at Camaching. These petitions were granted on June 23, May 10, and May 16, 1856, respectively.

An application by Fernando de los Cajigas for a mine of titaniferous iron at Cupang, which was conceded in 1850, is also to be referred apparently to Camaching, although the Camaching ore is scarcely to be described as titaniferous. Cupang is situated near Acle, and is connected by trail with Camaching. Jagor,[27] who visited Cupang in 1859, speaks of iron mines which were being worked by an Englishman. Possibly this Englishman, who is remembered by the Filipinos in the mining industry to-day and whose smelter site is shown on old maps, obtained possession of his mine through the concession granted to Cajigas.

According to the records, the claim San Pio Quinto at Camaching was granted to Pablo Carlos on December 7, 1883, but at the present time San Pio Quinto and other claims at Camaching are held by Joaquin and Francisco de la Concha, heirs of the earlier locators of the same name. In the following table is a list of all the mining claims in the Bulacan iron-ore region that are recorded in the archives of the Inspección de Minas.

TABLE II.—*List of Spanish iron-mining claims, Bulacan Province.*

Name.	Claims.	Area.	Owner.	Location.	Date of concession.
		Sq. m.			
De Hison	1	111,798.16	Heirs of Hison	Bacal Creek, Maon	Apr. 25, 1819
De Concha	2	125,772.93	Heirs of Concha	Bacal Creek, Camaching.	June 23, 1856
Constancia	2	300,000.00	Francisca Talag	Pinugayan Creek	Aug. 13, 1880
San Pio V	2	300,000.00	Pablo Carlos	Bacal Creek, Camaching.	Dec. 7, 1883
Sapang-Munti	1	150,000.00	Francisco Sanchez	Montamorong	June 9, 1893

Recently claims have been located on the minor ore deposits at Tumotulo, Macatalinga, Mayapa, and Tagpis, but no patents have been issued. The Angat Iron Mining and Smelting Company, a corporation composed largely of Filipinos, controls the Montamorong and Macatalinga properties, and another corporation, the Constancia Iron Mining and Smelting Company, is attempting to establish its title through the heirs of the former

[27] Reisen in den Philippinen. Wiedmann'sche Buchhandlung, Berlin (1873).

owners to the Constancia and Santa Lutgarda properties, which are being worked in the meantime by the descendants of Santiago Hison.

Iron smelting in the Philippines between the years 1784 and 1797 appears from the scant description on the record to have accomplished first a reduction of the iron into balls (*bolas*) or pasty masses which must have been somewhat malleable since bolos and other forged implements were made from them.[28] The first smelting was undoubtedly done under the guidance of Spaniards, and can scarcely be spoken of as a Filipino process, but the present-day smelting bears less evidence of the influence of the Spaniards than that of the Chinese, and is apparently unique in many respects.

The modern process has been described accurately and in detail by McCaskey.[29] In it no attempt is made to produce anything other than cast-iron plowshares and plowpoints. On this account, the smelting process differs somewhat from the native practice in Borneo, which produces a malleable iron and with which Becker [30] has compared the Bulacan smelting.

MINING

In 1913 there were 10 furnaces in operation in the Bulacan region—2 at Montamorong, 3 at Hison, and 1 at each of the deposits, Camaching, Santa Lutgarda, Santol, Tumotulo, and Macatalinga. The practice in mining and smelting is similar at each of these places, and the materials used in building the furnaces at several of the smelters come from the same locality. Some of the furnaces use ore containing only 50 per cent of iron, but usually these ores are enriched by addition of scrap iron to the charge. The smelting process has not changed materially within the last fifty years. During the last few months, however, several of the operators have been experimenting by using different clays for the furnace lining or by adding small quantities of limestone to the charge.

The mining will require little description since it involves only the breaking up of bowlders with hammers and bars or of scraping the ore out of the shallow pits by similarly simple methods. The ore is mined and sorted by the same laborers who carry it in baskets to the smelter. The location of a smelter is

[28] Buzeta, Manuel, and Bravo, Felipe. Diccionario geografico, estadistico, historia de Filipinas. Peña, Madrid (1851), 21.

[29] *Loc. cit.*, 55 et seq.

[30] *21st Annual Rep. U. S. Geol. Surv.* (1901), 584.

conditioned almost wholly on the situation of the charcoal, since the ore can be carried over a distance of from 2 to 3 kilometers to better advantage than can the charcoal.

SMELTING

The smelter.—The smelter building or camarin consists of a thatched gable roof about 16 meters wide by 22 meters long set up so as to cover the furnaces and an additional space sufficient for a train of molds, a storeroom for iron, a charcoal bin, an ore pile, a core-burning pit, a blast apparatus, and rather restricted quarters for the employees. At least three sides of the building are left open, the fourth side usually being closed by the charcoal bin which occupies about one-fourth of the total floor space.

Generally two furnaces, which are alternately in blast and in repair, are set up in the center of the smelter. Behind, and between them and the charcoal bin, is the one blowing apparatus which serves each furnace in turn. A train of about 15 double molds extends around the perimeter of the smelter. The storeroom for iron may be small, but is always strongly built and is kept locked to prevent theft. The ore pile is about a meter square, and serves as a breaking floor for reducing the ore to the required fineness as well as a stock pile. A small pit at one side of the furnaces is used to bake the clay cores which are placed in the plowpoint molds, and near it the core maker works, forming core, tuyeres, and molds, which are all of clay.

The furnaces are cylindrical stacks 2.25 meters in height and 1.5 meters in exterior diameter. The upper part of the stack to a depth of 1.75 meters is hollow, and constitutes the smelting crucible which is shaped like an inverted truncated cone with a diameter of 1 meter at the top of the furnace and about 0.5 meter at the bottom or truncated section of the cone. The stack is pierced from front to back through the bottom of the crucible by a rectangular hole or runner, 12 centimeters deep and 13 centimeters wide. The front end of this runner, constricted somewhat by a temporary clay bridge, serves as a tap hole for both iron and slag, while the rear end of the runner admits a single tubular clay tuyere through which the blast enters. Below and in front of the tap hole is a bench or step upon which a hand ladle, also made of clay, is placed to receive the iron upon tapping.

The walls of the furnace are soft-burned brick made of clay and set in a mortar of the same clay. The clay used for this

purpose by several of the smelters is the residual clay which results from the decomposition of the granite. A chemical analysis of this clay appears in Table XI, page 254. Before each smelting-run the sides of the crucible and runner are lined or veneered with a mixture of clay and charcoal.

A feature of the furnace which is essential to successful smelting is a quartz-sandstone block 20 by 30 by 40 centimeters in size which is set in the wall of the crucible over the tap hole just where the blast, entering through the tuyere from the opposite side, will impinge upon it. This stone, which the Filipinos call *bato buga,* is more refractory than the furnace clay, and resists the highest temperature of the furnace at a point where without it the furnace wall would be quickly eaten through. These refractory stones for all the furnaces are obtained from the bedded quartz-sandstone at the base of the sedimentary series near the barrio of Bayabas.

The tuyere (*bombon*) is a tube 60 centimeters long, 6 centimeters in interior diameter, and 20 centimeters in exterior diameter, which is made of unbaked furnace clay.

The blowing apparatus (*joncoy*) is a hollow log, 35 centimeters in interior diameter and 3.5 meters long; it is fitted with a wooden piston which is edged with soft chicken feathers to prevent the leakage of air around it. The piston rod is long enough to permit a full stroke of the piston when worked back and forth by hand. The blower is double acting, wooden tubes conducting the blast from valves at both ends of the displacement chamber to the tuyere. In operation the blower lies almost horizontal, one end being raised slightly from the floor to facilitate the work of the operator.

The molds (*hormas*) are made of clay reënforced by rattan or occasionally by wire. Each mold consists of a base, which is fixed rigidly to a frame or rack, and a removable cover. One end of the frame rests always on the ground, but the other end can be raised to a seat on two crotched sticks so that the molds when in position to receive the metal are inclined at a convenient angle, about 40° from the horizontal, for pouring. The frames, together with the small posts upon which the raised ends rest, are called horses (*caballos*), and the usual equipment for a smelter includes a train of about 15 horses, 3 mounted with large single plowshare molds and the rest carrying each a pair of smaller plowshare or plowpoint molds.

Charcoal burning.—An essential attribute of the smelter is the cluster of charcoal kilns which surrounds it. There are some-

times as many as a half dozen charcoal kilns located at favorable places in the forest within convenient distances from the smelter. The Filipinos in the iron industry have evolved a useful and fairly efficient method of burning charcoal in connection with their smelting practice. Formerly, they burned their charcoal in pits, as is still the practice elsewhere in the Philippines. Abandoned charcoal pits may still be seen near the old smelting centers; they are often located in a side hill, and are circular in plan, 3 meters in diameter and 2 meters deep, with an opening or hearth on the down-hill side. A temporary covering or roof of green wood and earth was provided, and the fire was controlled by making this roof more or less impervious to the draft.

The charcoal kiln now in use is built of bamboo, and is entirely above the surface of the ground (Plate VI). It is called an *inglesa* for the reason, it is said, that an Englishman (*ingles*) who operated an iron smelter at Cupang in 1860 first used this type of kiln. An inglesa, or charcoal kiln, is simply a rectangular inclosure, the walls of which are made of bamboo poles; it is about 14 meters long, 4.5 meters wide, and 4.5 meters high. The logs for charcoal are cut into lengths 1 meter shorter than the width of the kiln, and are corded up inside the kiln with a space 0.5 meter wide everywhere between the pile and the bamboo walls. About 30 per cent of the wood in the kiln is in the shape of logs 0.5 meter or more in diameter, while the remainder is graded in size down to about 10 centimeters in diameter. Openings which run longitudinally along the floor of the kiln and up one end of the pile are provided for maintaining a draft. After the pile is completed, the space around it inside the walls is filled with fine charcoal waste and a cover of the same material is spread over the top. The fire is started at the lower end, and gradually burns through the kiln, being retarded by the smothering effect of the charcoal cover. Two burners are employed, who control the burning by opening vents through the walls at proper places as the carbonization progresses. By the time the burning is complete, the pile has subsided to a height of 2.5 or 3 meters. It requires anywhere from fifteen to thirty days to burn a kiln of 140 cubic meters of charcoal.

The charcoal is obtained in unusually large pieces, and is hard and strong. Where wood is cut for charcoal on mining claims, all classes of timber are utilized; the hard woods of the first- and second-group trees make splendid charcoal. Even where the wood is cut under license on public land and

the operator may use only third- and fourth-group woods, the charcoal obtained is first class. A cubic meter of wood yields 0.8 cubic meter or 14 bushels of charcoal, weighing 155 kilograms. The following table contains the proximate and the ultimate analyses of a representative sample of the charcoal produced, with a chemical analysis of the ash from the same sample.

TABLE III.—*Proximate and ultimate analyses of Bulacan charcoal and chemical analysis of the ash content.*[a]

	Per cent.
Proximate analysis:	
Moisture	4.48
Volatile combustible matter	11.23
Fixed carbon	81.17
Ash	3.12
Total	100.00
Ultimate analysis:	
Carbon	83.36
Hydrogen	2.82
Nitrogen	0.47
Oxygen (by difference)	6.75
Sulphur	trace
Total	100.00
Ash analysis:	
Silica (SiO_2)	2.89
Ferric oxide and alumina (R_2O_3)	12.58
Lime (CaO)	66.73
Magnesium oxide (MgO)	8.58
Potassium oxide (K_2O)	5.48
Sodium oxide (Na_2O)	3.65
Phosphoric anhydride (P_2O_5)	trace
Total	99.91

[a] Analyzed by T. Dar Juan, chemist, Bureau of Science.

The process of smelting.—The furnace is in blast night and day, and the following personnel is required for the two daily shifts: An administrative superintendent (*encargado*), who is also clerk and storekeeper; a technical superintendent (maestro), who is in charge of the smelting; an assistant maestro, who acts as maestro on the night shift; 2 mold men (*braganantes*),[31]

[31] The term "braganante" may have come into use through the work of the molders in continually raising and lowering the mold frames from the seat of forked sticks upon which they rest and in lashing and unlashing the mold covers. The root of the word appears to have an application in Spanish to a fork or crotch of a tree and in military usage to a rope used for lashing.

who are also slag men (*escoriadores*); and 4 blower men (*jiladores*). The success of the operation depends absolutely upon the maestro; competent maestros are scarce and comparatively well paid, although the rate of payment is based upon the quantity of iron produced. The mold men are called upon only at intervals to attend the pouring, empty the molds, or remove the slag, but they work day and night as do also the blower men. In addition to this smelter force, laborers are required for cutting wood, burning charcoal, and for breaking up the ore, and carriers (cargadores) are necessary for bringing the ore from the mine (*tibagan*) and the charcoal from the kiln to the smelter, for transporting the finished product from the smelter to town, and for bringing in food supplies.

When it is desired to blow in a recently constructed or repaired furnace, a slow fire is started in the crucible and allowed to burn for several hours; then charcoal is added until the crucible is filled and a light blast applied. About twenty-four hours after the fire is kindled, the blast is increased and a small quantity of ore together with more charcoal is charged in at the top of the furnace. Increasingly larger charges are now added at intervals until the operation is normal and the furnace is in full blast. Afterwards, ore and charcoal are charged together at intervals of from one to five hours depending on the rate at which the iron comes down. The average charge consists of 43 kilograms of charcoal and 25 kilograms of ore. Charcoal and ore are each distributed evenly over the top of the burden. The ore is broken into pieces with a maximum diameter of about 2 centimeters.

When the furnace is working normally, iron is tapped off from two to five times per shift. As soon as the reduction of the ore begins, the lining of the crucible is attacked and eaten away to supply the necessary flux for the slag. In this way a small depression below the level of the runner is very soon formed in which the liquid iron collects. In tapping, the clay bridge with which the tap hole is partly closed between tappings—although for some reason the tap hole is always left partly open and at each stroke of the blower a tongue of flame rushes through it—is removed, and the maestro with a long iron rod proceeds to pull out first the ropy, viscous slag which is floating on the iron in the bottom of the crucible. As the slag is drawn forth, it is allowed to fall into the ladle which is thus preheated before it receives the iron. The slag is pasty enough to adhere to the end of the rod, and the maestro, working the last of it into a ball, improvises a rake with which he draws

the molten iron forward so that it spills out over the lip of the tap hole into the ladle.

The iron is poured from the ladle directly into the molds, a cover of floating charcoal preventing the oxidation of the surface of the metal while in the ladle. The plowpoints are cast hollow by pouring around a suitable clay core. The only parts of the casting which necessitate the use of molding sand are the projecting rods on the bottom of the shares by which the shares are clamped to the plowbeam. To provide for these, the share molds have a core box into which molding sand, consisting of a pulverized mixture of clay and charcoal, is pressed around 4 small sticks, so placed that the spaces left upon their removal serve as molds for the rods. After each pour, the mold is opened, the casting removed, and the surfaces of the mold carefully inspected for broken places. All cracks and flaws are patched up with clay, and the surfaces are painted with a charcoal paint.

The smelting continues as long as the furnace works well or until no more iron can be brought down, ordinarily for a period of from twelve to fifteen days. Occasionally a furnace cannot be made to work properly, and is allowed to "die" after four or five days' trial. In such cases, the lining of the crucible is removed and a new lining built up. After a run, the furnace is cleaned and relined, and is then ready to be again blown in.

Capacity of the furnaces.—The following table shows the production in pairs [32] and in kilograms per day and per smelting run for 4 furnaces. The first three are ordinary runs, while the last is the record run for the district. It will be noted that there is little evidence of a decrease in production toward the end of the runs. This is due to the tendency to stop the smelting whenever, after the usual length of time, the furnace shows signs of working badly, instead of continuing until no more iron is reduced.

[32] Plowshares (*lipias*) are made in three sizes and plowpoints (*sudsuds*) in one size (Plate V). They are counted and sold in pairs (*pares*), which consist in the cases of the points and each of the two smaller plowshares of two castings, but each one of the larger plowshares constitutes a pair. A first-class pair (1 large plowshare) weighs 3.2 kilograms; a second-class pair (2 smaller plowshares), 4.0 kilograms; a third-class pair (2 plowshares), 2.5 kilograms; and a pair of points weighs 5 kilograms.

TABLE IV.—*Output of various furnaces per day and smelting run.*

FURNACE No. 1.

Number of days furnace in blast.	Plowshares produced.			Plow-points produced.	Total.	
	First size.	Second size.	Third size.		Pairs.	Kilos.
	Pairs.	*Pairs.*	*Pairs.*	*Pairs.*		
1	4	10	6	30	50	192
2	9	13	9	49	80	294
3	12	9	9	40	70	258
4	5	5	5	25	40	148
5	15	15	12	58	100	366
6	16	15	10	59	100	368
7	12	13	9	46	80	294
8	12	14	10	44	80	290
9	10	10	5	25	50	176
Total	95	104	75	376	650	2,386
FURNACE No. 2.						
1	3	6	4	29	40	156
2	4	8	5	43	60	224
3	7	20	13	40	80	288
4	6	20	11	43	80	286
5	5	20	11	44	80	286
6	4	10	10	36	60	214
7	3	10	10	37	60	214
8	6	10	14	40	70	250
9	2	8	7	43	60	222
10	4	10	10	36	60	214
11	4	9	8	39	60	220
12	4	7	7	32	50	182
13	8	16	9	27	60	210
14	6	16	8	20	50	172
15	----------	2	5	19	26	94
Total	66	172	132	526	896	3,232
FURNACE No. 3.						
1	8	6	6	20	40	146
2	14	14	11	41	80	290
3	15	12	11	32	70	252
4	20	10	10	50	90	334
5	20	10	10	60	100	374
6	27	25	8	40	100	364
7	25	20	4	51	100	374
8	27	12	8	43	90	336
9	30	14	8	49	101	378
10	23	15	6	36	80	296
11	18	9	3	30	60	228
12	19	13	6	42	80	280
13	19	12	6	32	70	256
Total	265	173	97	526	1,061	3,918

TABLE IV.—*Output of various furnaces per day and smelting run*—Contd.

FURNACE No. 4.

Number of days furnace in blast.	Plowshares produced.			Plow-points produced.	Total.	
	First size.	Second size.	Third size.		Pairs.	Kilos.
	Pairs.	*Pairs.*	*Pairs.*	*Pairs.*		
1	14	6	10	10	40	138
2	15	15	21	29	80	272
3	15	18	18	29	80	274
4	21	21	20	38	100	350
5	20	23	24	43	110	380
6	20	20	21	49	110	388
7	25	21	17	47	110	394
8	23	23	23	51	120	422
9	22	20	20	48	110	390
10	20	21	19	50	110	390
11	22	20	20	48	110	390
12	20	21	20	39	100	350
13	20	17	18	45	100	356
14	22	16	17	45	100	358
15	20	19	19	42	100	352
16	20	17	17	46	100	358
17	24	18	19	49	110	392
18	23	21	16	50	110	396
19	14	9	15	62	100	370
20	20	26	19	55	120	424
21	16	24	18	42	100	368
22	12	30	23	40	105	356
23	6	19	15	20	60	198
24	20	26	26	48	120	410
25[a]	20	27	24	46	117	424
Total	474	498	479	1,071	2,522	8,900

[a] Furnace blown out for lack of charcoal.

The tabulated records show that the process yields from 200 to 400 kilograms of metallic iron per day from each furnace, but it is probable that 250 kilograms, or about 80 pairs, is a fair average figure for daily runs throughout the district.

Efficiency of the smelting process.—The following table sets forth the data with respect to the smelting industry in 1913, from which an idea of efficiency of the process can be obtained.

TABLE V.—*Statistics of iron smelting in 1913.*

NUMBER, WEIGHT, AND VALUE OF PAIRS PRODUCED.

	Pairs.	Tons.	Value.
First class	12,440	40.4	₱13,684
Second class	9,147	36.6	13,720
Third class	13,006	36.0	12,006
Points	22,783	113.7	25,061
Total	56,376	226.7	64,471

Furnaces in blast		10
Smelting runs (*cendidas*), all furnaces		61
Days in blast, all furnaces		657
Ore used	tons	555
Calculated weight of iron in ore [a]	do	333
Charcoal used	do	960
Average length of furnace run	days	11
Days in blast (average for each furnace for the year)		66
Pairs per day in blast (average)		86
Iron per day in blast (average)	kilos	345
Ore required per ton of iron smelted	tons	2.45
Charcoal used per ton of iron smelted	do	4.23
Efficiency of Filipino process, per cent extraction		68
Value of product per ton		₱284.00

[a] Metallic iron assumed to constitute 60 per cent of ore.

About 68 per cent of the iron in the ore is extracted by the process. The loss of iron is not due, however, to the production of a ferrous slag but, as will be shown presently, to the carrying off of pellets of iron and pieces of unreduced ore which are mechanically inclosed in the slag.

Metallurgy of the smelting process.—The cast iron produced in Bulacan is uniformly a white fine-grained iron which is low in silicon, contains very little graphitic carbon, and is extraordinarily hard. Due probably to its hardness, the iron is very satisfactory in the use to which it is put and the implements made from it are much preferred by the farmer to those made from imported pig iron. The properties of the iron can be explained by the low temperature at which it is reduced and cast and the rapidity with which the castings cool. Analyses of the product appear in the following table. Sample 13a is an unusual iron produced in the Hison smelter and cast at the end of an unsuccessful run of three days; the difficulty in this run was explained by the maestro as due to the presence of quartzose ore (*bacal sigay*) in the charges. Sample 99 is the typical Hison iron, and sample 100 is the usual Montamorong product.

TABLE VI.—*Analyses of iron produced by Filipinos from Bulacan iron ores.*[a]

Constituent.	Sample No.—		
	13 A.	99.	100.
	Per cent.	*Per cent.*	*Per cent.*
Silicon (Si)	1.520	0.070	0.620
Sulphur (S)	0.044	0.070	0.089
Phosphorous	0.115	0.053	0.130
Manganense (Mn)	0.101	0.127	0.091
Total carbon (C)	5.640	3.840	3.790
Graphite carbon	1.600	0.198	0.232
Iron by difference (Fe)	92.580	95.840	95.280
Total	100.000	100.000	100.000

[a] Analyzed by T. Dar Juan, chemist, Bureau of Science.

The statement has been very commonly made that the Bulacan ores are self fluxing, and the conclusion would be natural to one who made a short visit to a smelter while the furnace was in blast, since there would be observed only the charging of ore and fuel and the tapping of the reduced iron, with no evidence of the addition of fluxes. If, however, the observer has an opportunity to watch the repair of a furnace at the end of a successful run, he must get an entirely different impression. On blowing out, the crucible is usually found to be somewhat deepened and to be enlarged at least 50 per cent in diameter; moreover, throughout the smelting the clay tuyeres are gradually consumed through the eating way of the hot end, and consequently must be renewed every two to three days. The quartz-sandstone block on which the blast plays is the only part of the crucible which is not slagged away in considerable proportion. It is indeed very probable that the necessity for the periodic closing down of the furnace is due not alone to the mechanical irregularity caused by the enlarged section of the crucible but also to the circumstance that through the same cause the flux which the ore demands becomes less readily available.

That the ore does demand the addition of fluxes to form a fusible slag becomes evident upon study of typical ore analyses. Calculating the proportions of the principal constituents in the slag which the Hison ore (analysis 6) without any flux would yield, if all the iron in the ore were reduced and carried with it 1 per cent of its own weight in silicon, the following result would be obtained.

TABLE VII.—*Calculated composition of slag from Hison iron ore (unfluxed).*

Constituent.	Per cent.
Silica (SiO_2)	39.2
Alumina (Al_2O_3)	44.5
Lime (CaO)	2.5
Magnesia (MgO)	13.8
Total	100.0

A slag of this composition would generally be considered as undesirable for blast furnace work, and it is doubtful if it could be fused at the low temperature which prevails in the Bulacan furnaces. It is true, of course, that even in the absence of fluxes the slag actually obtained would differ from the calculated slag in composition because of the facts that (1) not all the iron is reduced, (2) the reduced iron contains less than 1 per cent of silicon, and (3) the ash from the excessive quantity of charcoal used goes into the slag. If allowance be made for the ash from 172 parts of charcoal for every 100 parts of ore, if 0.5 of silicon be allowed for the iron produced—a proportion which to judge from the analysis of cast iron in Table V is not far from representative—and if the slag be assumed to contain 1 per cent of ferrous oxide, the slag from Hison ore (sample 6) should have about the composition shown in the following table.

TABLE VIII.—*Calculated composition of slag from Hison ore (sample 6), modified by charcoal ash.*

Constituent.	Per cent.
Silica (SiO_2)	28.4
Alumina (Al_2O_3) [a]	30.1
Ferrous oxide (FeO)	1.0
Lime (CaO)	26.1
Magnesia (MgO)	11.0
Potassium oxide (K_2O)	2.0
Sodium oxide (Na_2O)	1.4
Total	100.0

[a] The alumina as calculated includes also the ferric oxide in the ash of the charcoal.

Even as modified by the charcoal ash the slag is still undesirable, principally because of the high alumina, and as a matter of fact is quite different from the slag actually obtained in practice.

The composition of Bulacan slags is shown in the following table. Sample 13 is an unusual slag obtained under the conditions stated in connection with the analysis of sample 13a of

cast iron. Sample 27 is a representative sample of the slag from the Hison furnace. The first two columns show the actual analyses of the slags as received; the last two columns show the same analyses recast so as to exclude a portion of iron which was found by magnetic separation and analysis to be present in the slag as metallic shot and pellets.

TABLE IX.—*Analyses of slags from Bulacan blast furnaces.*[a]

Constituent.	Sample No.			
	13.[b]	27.[b]	13.[c]	27.[c]
	Per cent.	*Per cent.*	*Per cent.*	*Per cent.*
Silica (SiO_2)	60.36	49.94	63.90	55.10
Ferric oxide (Fe_2O_3)	13.16	10.75	----------	----------
Ferrous oxide (FeO)	----------	----------	7.88	1.25
Alumina (Al_2O_3)	15.85	14.50	16.80	16.10
Lime (CaO)	5.82	16.80	6.16	18.63
Magnesia (MgO)	0.88	3.22	0.93	3.58
Titanium oxide (TiO_2)	0.55	0.48	0.58	0.53
Manganese oxide (Mn_3O_4)	trace	trace	----------	----------
Sodium oxide (Na_2O)	2.45	2.34	2.59	2.60
Potash (K_2O)	1.10	1.99	1.16	2.21
Sulphur (S)	trace	trace	trace	trace
Total	100.17	100.02	100.00	100.00

[a] Analyzed by T. Dar Juan, chemist, Bureau of Science.
[b] As received.
[c] Free from metallic iron.

If now the analyses of the calculated slag including charcoal ash and the actual slag in the following table be compared, a difference will be apparent which is the result of the fluxing action of the furnace walls and the tuyeres. In these analyses, which are directly comparable, the magnesia and minor constituents have been summated to their lime equivalent, in order to show more clearly the general character of the slags.

TABLE X.—*Analyses of actual and calculated slags from Hison ore (sample 6).*

Constituent.	Calculated.	Actual.[a]
	Per cent.	*Per cent.*
Silica (SiO_2)	27.4	55.1
Alumina (Al_2O_3)	29.2	16.1
Lime (CaO) (summated)	43.4	28.8
Total	100.0	100.0

[a] Slag 27; analysis recast to exclude metallic iron.

The analysis of the calculated slag is far outside the limits usually set for a white iron smelted with charcoal, the silica being much too low and the alumina much too high. The actual slag, on the other hand, conforms very closely to the well-known, most fusible slag of Bodeman, which requires silica, 56 per cent; alumina, 14 per cent; and lime, 30 per cent.

Practically the only modification required to bring the calculated slag to conformity with the actual slag is the addition of silica; the proportion of summated lime constituents increases very slightly. Thus it appears that in the smelting process as practiced an ideal slag is formed automatically by the selective action of the charge on the crucible walls and that silica is the principal constituent so acquired. If the ore is to be smelted in a permanent furnace, therefore, as several of the operators desire, the flux required is not lime particularly, so long as the excessive consumption of charcoal is maintained, but silica, and it becomes clear from this data why the operators who have recently been adding limestone to their charge have not benefited thereby. It might be possible, however, to reduce the fuel consumption somewhat by the addition of lime, because in current practice fuel is demanded not only for requisite temperature but also to augment the bases in the slag.

Nothing is more evident than that the heat is insufficient in the present type of furnace. The iron comes out just above the freezing point, and although the slag requires silica the quartz in the sandstone block which forms part of the crucible lining is not attacked; presumably the temperature is not high enough to make silica in this form available. Even the fusible slags obtained are viscous and stiff enough to cause great loss through the removal of mechanically contained iron. The principal obstacle to the attainment of a higher temperature is probably the insufficiency of the blast, which is obviously lacking in volume and in constancy, together with the shortness of the stack and the impermeability of the burden of fine ore.

The Bureau of Science is conducting a series of metallurgical experiments on Philippine iron ores including those from Bulacan, and will ascertain from this work just what fluxes are required and in just what proportion the fluxes available are to be employed with the various ores; therefore, it is not planned to go further into this problem here. One thing, however, should be pointed out. If the Bulacan ores are to be smelted in modern furnaces with refractory linings, one of the principal required fluxes for the ores now in use will be silica. Yet all the furnace ores which carry silica in the form of quartz are

now being discarded as unsuited to the present smelting process. Obviously, this siliceous ore should be utilized; it can be utilized, and at the same time the required increase of silica in the slag can be effected by blending it with the pure ores.

Limestone, which will be required as a flux if modern methods are introduced, is available in the vicinities of all the ore deposits. The Binangonan limestone is most uniform and widespread, and would make an efficient flux. Analyses of the Binangonan limestone, together with an analysis of the residual clay which serves as a flux in the present smelting process, appear in the following table.

TABLE XI.—*Analyses of Binangonan limestone and a residual clay, Bulacan iron ore region.*

Constituent.	Sample No.		
	5-45.[a]	7-45.[a]	33.[b]
Moisture	0.12	0.26	2.15
Silica (SiO_2)	1.25	0.61	58.61
Ferric oxide (Fe_2O_3)	0.38	0.52	7.39
Alumina (Al_2O_3)			23.31
Lime (CaO)	53.01	53.98	0.90
Magnesia (MgO)	1.38	1.12	0.99
Potash (K_2O)	0.14	0.11	trace
Sodium oxide (Na_2O)	0.62	0.46	1.94
Loss on ignition	43.38	43.44	
Total	100.28	100.50	95.29

[a] Binangonan limestone, vicinity of Bagum Barrio; analyzed by L. A. Salinger, chemist, Bureau of Science.

[b] Clay from decomposed granite near Hison; analyzed by T. Dar Juan, chemist, Bureau of Science.

Cost and value of iron produced.—The cost of a smelter fully equipped varies from 900 to 2,500 pesos. If the site is distant from clay suitable for furnace and mold construction, if two furnaces are erected and the smelter is roofed with sheet iron, the cost approaches the higher figure. If the furnace clay is at hand, if only one furnace is erected and the roof is made of palm leaves or grass, the smaller sum will suffice.

The cost of smelting and marketing the castings varies with the distance of the smelter from charcoal, ore and clay deposits, and from market.

The cost of charcoal varies from 10 to 20 pesos per metric ton, equivalent to about 90 bushels. An average cost based on the actual expenditure for 4 separate kilns is 14.75 pesos per ton.

The cost of transportation from smelter to market varies from 0.05 peso to 0.30 peso per pair, depending on the distance

involved. The transportation of clay, ore, and charcoal to the smelter varies from 0.14 to 1.00 peso per 100 kilograms according to the distance; this item may amount to as much as 0.10 peso per pair of castings.

The smelter employees are paid on the basis of 1,200 pairs of castings. For 1,200 pairs of castings, the maestro and his assistant each receive from 30 to 50 pesos; the 2 mold men, 20 to 25 pesos; and the blower men, about 10 pesos. The encargado receives from 12 to 15 pesos per month, and the core maker who is usually also a mold man receives 0.50 peso per 100 cores and from 0.15 to 0.20 peso for each tuyere. Laborers receive from 0.30 to 0.80 peso each per day. The regular employees around the smelter are supplied with food by the operator.

The castings sell for from 0.80 to 1.10 pesos per pair. They are marketed throughout Bulacan and the adjacent provinces wherever rice is grown, the plows being used generally for rice culture. By manufacturing castings from his iron ore, the operator receives from 250 to 300 pesos for his product, whereas if he sold it as pig iron he could not hope to get more than 60 pesos per ton for it.

A careful record of production and costs for 7 smelters covering a period of two months in 1912, during which time the total number of days of smelting operation for all furnaces was ninety-two, yielded the following data. The furnaces consumed about 65 tons of ore and 112 tons of charcoal, and produced 7,249 pairs or a little more than 26 tons of castings. The total cost of these castings, including costs of the charcoal, mining, smelting, repairs, molds, transportation, subsistence, marketing, and general expense, was 4,375 pesos. The market value of the product was 7,100 pesos, yielding a total profit of 2,725 pesos or a profit of nearly 0.38 peso per pair.

Statistics of production.—The following table shows the quantity and value of the iron produced in the Philippines from the date of the earliest records to the end of the year 1913. During the last fifty years the whole production has come from Bulacan and has been made up exclusively of plowshares and plowpoints. It appears from the records that the industry was larger in 1884, when it centered around Camaching, than it is at present. At that time Camaching produced about 30,000 pairs annually, while the other properties combined produced 28,400 pairs. Today, Camaching is credited with a scant 10 per cent of the total production.

In addition to the plow castings smelted from iron ore in Bulacan, the Chinese foundrymen in Manila make the same im-

plements from imported pig iron. Accurate figures as to the size of the Chinese production are not obtainable, but it is probably larger than that of the Bulacan operators. The Chinese casting is considered by the farmer to be inferior to the Bulacan casting, and brings only a little more than half as much on the market.

The annual production has increased until it is now worth more than 50,000 pesos, and it could probably be materially increased if through a lowering of prices on the part of the Bulacan smelters the Chinese castings could be crowded out of the market.

TABLE XII.—*Quantity of iron ore mined and quantity and value of iron produced in the Philippines, 1664–1913.*

Years.	Iron ore.	Cast iron.	Value.
	M. tons.	*M. tons.*	*Pesos.*
1664–1883	[a] 8,000	2,500	350,000
1884	300	115	25,040
1885–1901	[a] 2,000	600	70,000
1902	160	56	6,400
1903	200	70	15,900
1904	350	123	20,170
1905	320	116	18,400
1906	350	125	18,000
1907	180	132	19,536
1908	290	96	17,500
1909	234	78	31,078
1910	150	50	20,023
1911	219	73	29,159
1912	352	141	49,272
1913	555	227	64,471
Total	13,960	4,617	754,949

[a] Estimated.

UTILIZATION OF THE IRON ORES

The present industry whereby a few hundred tons of ore are smelted each year for the manufacture of cast-iron plows, the life of which is rarely more than two seasons, is not an adequate nor an economic utilization of the Bulacan iron ores. While the ore reserves do not contain the vast tonnages that characterize so many deposits in America, it appears from this study that there are available at least a million tons and probably several million tons of ore in the Bulacan region. Considering the present consumption of iron and steel in the Philippines, 40 to 50 thousand tons annually, this district might supply ore for an iron and

steel plant appropriate in size to the market over a period of time long enough to redeem the capital invested. Such a plant would have to manufacture its pig iron into standard forms, plates, rods, rails, etc., since the local market uses comparatively little pig iron or steel.

The exportation of iron ore from the Philippines is prevented at present by the collection of a wharfage tax of 2 pesos per ton on exports of ore. Even if this tax were removed, it is questionable if the Bulacan ores could be exported advantageously because of their situation so far from a seaport.

Recent progress in the electric smelting of iron and steel has been attended with the design of plants which, although complete in themselves, are of limited capacity. At Domnarfvet, Sweden, for instance, a commercial plant for electric iron smelting has been erected [33] which has only one furnace capable of reducing about 11,000 tons of pig iron per year, and at Hagfors, Sweden, is a similar plant with two furnaces which together will produce about 18,600 tons of pig iron annually. Both of these plants, it is said, are in successful operation; they are modeled after an experimental plant which was built at Trollhättan, Sweden, at a cost of less than 200,000 pesos and which demonstrated conclusively the feasibility of commercial operation on this scale. Electric furnaces for steel manufacture are designed in similarly small units. The smaller iron furnaces require about 2,250 kilowatts of electricity, and another furnace to make steel out of the pig iron produced would require an additional 500 kilowatts according to the estimates of the writers quoted above.

Coking coal occurs only in limited quantity, so far as is known, in the Philippines; in Bulacan no commercial coal has been discovered. The forests in the iron-ore region, however, appear to offer an abundant supply of charcoal, a reducing agent which is peculiarly adapted to present practice in electric smelting; coke, as a matter of fact, has not been used successfully in the Swedish type of furnace.

The greatest obstacle in the way of development in Bulacan is the isolation of the ores in a mountainous region. Transportation difficulties are involved, no matter where the smelting site is located. In this respect the exploitation of the Bulacan ores presents severer problems than would attend the utilization of other iron-ore resources in the Philippines, notably

[33] Lyon, Dorsey A., and Keeney, Robert M., *Bull. U. S. Bur. Min.* (1914), 67, 27.

the hematite and magnetite ore at Mambulao Bay, Camarines. This condition may defer operations on a larger scale in Bulacan.

Because of their location, it is probably not practicable to erect a reduction plant at the site of any of the ore deposits. If the plant cannot be located at the ore deposits, its situation will be determined by the market and electrical power factors. The possibilities of long-distance transmission of electric current leaves the manufacturing site independent within certain limits of the power-plant site. Market requirements will best be met if the plant is established at Manila itself, although some advantage in shorter transportation of ore, flux, and charcoal would be gained and the market would still be close at hand if a site at the head of navigation on Angat River were selected.

Aërial cableways offer the best solution of the problem of getting the ore down out of the mountains. By providing suitable intermediate loading stations, charcoal and limestone flux could be brought down on the ore cableway. The cableway might possibly be extended to a point where water transportation was available; if any intermediate haul were necessary, it would be short and through level country. So far as can be ascertained in advance of exploration, the largest supply of ore is at Camaching, but intelligent prospecting by diamond-drill methods, which should precede actual development, might reveal larger ore reserves elsewhere. With suitable branch cableways, ore would be taken from several of the deposits at the same time.

The vicinity of Polo a short distance above Matictic, on Angat River, has been proposed as a tentative site for hydroelectric development by Col. C. de las Heras, an engineer in the Spanish army who was formerly in charge of water supply for the city of Manila. Practically the same site is contemplated in preliminary plans by the Bureau of Public Works for the development of electricity in connection with an irrigation project which would secure water from Angat River. The irrigation division of the Bureau of Public Works maintained a gauging station at Polo throughout the years 1910 and 1911. Their records show a minimum flow of 7,000 and a maximum flow of 1,198,000 second liters of water in Angat River at this point during the period covered by their observations. Colonel Heras's estimates show that at ordinary stages of the river 5,800 kilowatts, and at the lowest stage a minimum of 3,700 kilowatts of electrical power, could be generated if a suitable dam were constructed across Angat River, a short distance above Polo.

According to the data already quoted concerning electric smelting installation in Europe, 3,700 kilowatts would more than meet the power demands of a plant consisting of two small furnaces, one for iron and one for steel manufacture. The excess power over that required for smelting would hardly be sufficient at the lowest stages of the river for the operation of the cableway to the ore deposits and the machinery for working up the iron and steel into marketable forms, but during the greater part of the year there would be ample power for all purposes.

Electric furnaces, therefore, appear to be an important consideration in connection with the future exploitation of Bulacan iron ores. The fundamental requirements of a small iron and steel industry are met in the conditions which obtain in Bulacan.

ILLUSTRATIONS

TEXT FIGURES

FIG. 1. Outline map of central Luzon, showing situation of the Bulacan iron-ore mining region with respect to Manila.

2. Stratigraphic column for the Bulacan iron-ore region.

3. Geologic sections through the iron-ore region, diagrammatic in part: (*a*) Post-Miocene sedimentaries; (*b*) Miocene sedimentaries; (*c*) granite; (*d*) effusives with intrusives; (*e*) intrusives with effusives.

4. Geologic section through ore body at Camaching, along an east-west line; diagrammatic in part: (*a*) Miocene shales, tuffs, and clastics; (*b*) altered wall rock; (*c*) iron ore; (*d*) intrusives; (*e*) blocks of limestone in ore; (*f*) limestone and clastics; (*h*) effusives; length of section, about 200 meters.

5. Geologic section through ore body at Montamorong, along a northeast-southwest line; diagrammatic in part: (*a*) Granite; (*b*) intrusives; (*c*) altered wall rock; (*d*) iron ore; (*e*) effusives; length of section, about 100 meters.

6. Geologic section through ore body at Hison, along an east-west line; diagrammatic in part: (*a*) Granite; (*b*) intrusives; (*c*) altered wall rock; (*d*) iron ore; (*e*) effusives; (*f*) limestone, shale, and sandstone; length of section, about 200 meters.

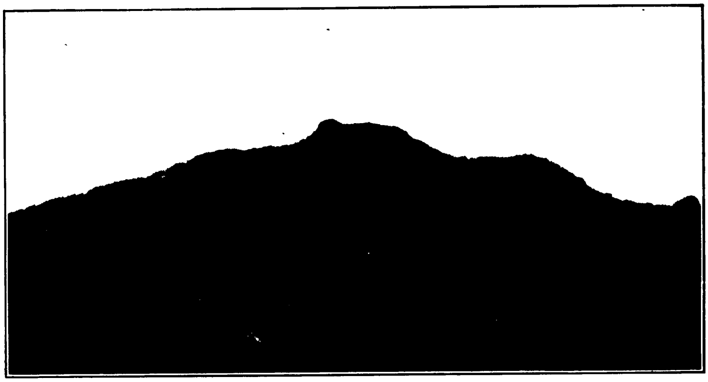


Fig. 1. Binangonan limestone in Mount Bahay Panique (home of the bats); looking southwest.

Fig. 2. Typically forest-covered slope in iron-ore region; Mount Mayapo.

Fig. 3. Balubad Falls in bedded tuff; Balaong River.

PLATE I.

Fig. 1. Granular magnetite in fibrous amphibole (tremolite ?), hanging wall Constancia ore body; natural size.

Fig. 2. Specimen across wall of magnetite vein in limestone, Camaching; natural size.

PLATE II.

Fig. 1. Magnetite vein in limestone. Camaching.

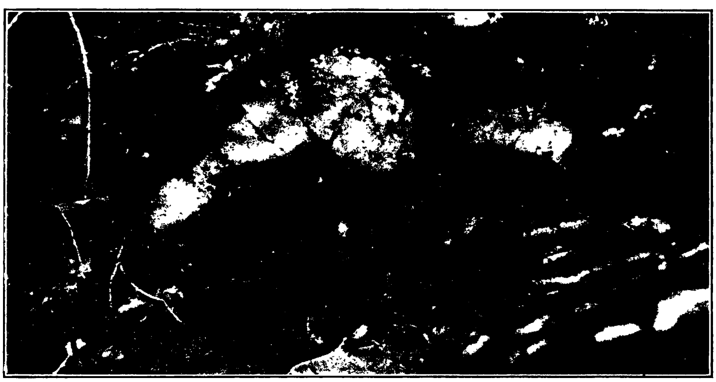


Fig. 2. Inclusions of limestone in iron ore, Camaching.

Fig. 3. Diabase (?) dike in diorite, Bayabas River; quartz filling along fractures.

PLATE III.

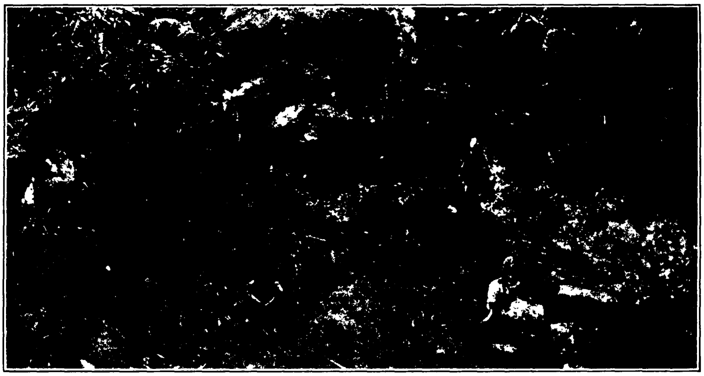


Fig. 1. Ore pit at Hison ore body.

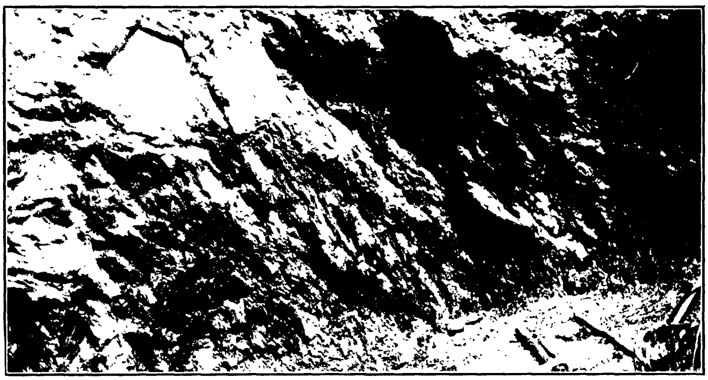


Fig. 2. Ore face in pit at Montamorong.

Fig. 3. Large hematite bowlder in stream below ore body, Santa Inez.

PLATE IV.

Fig. 1. Filipino blast furnace in operation, Mayapo.

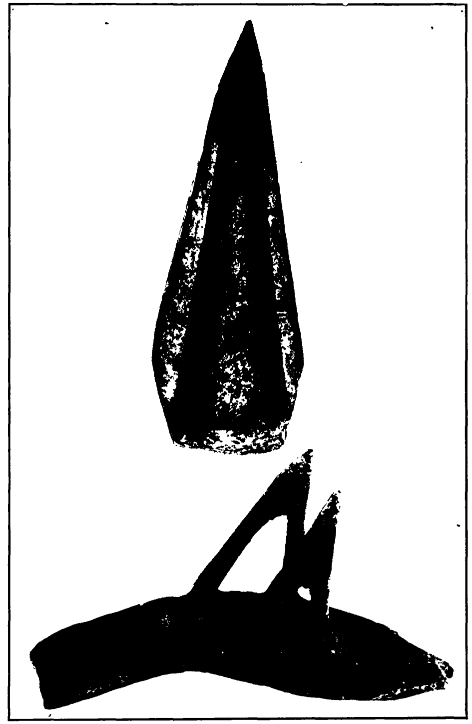


Fig. 2. Cast-iron plowshare and plowpoint produced by Filipinos in Bulacan.

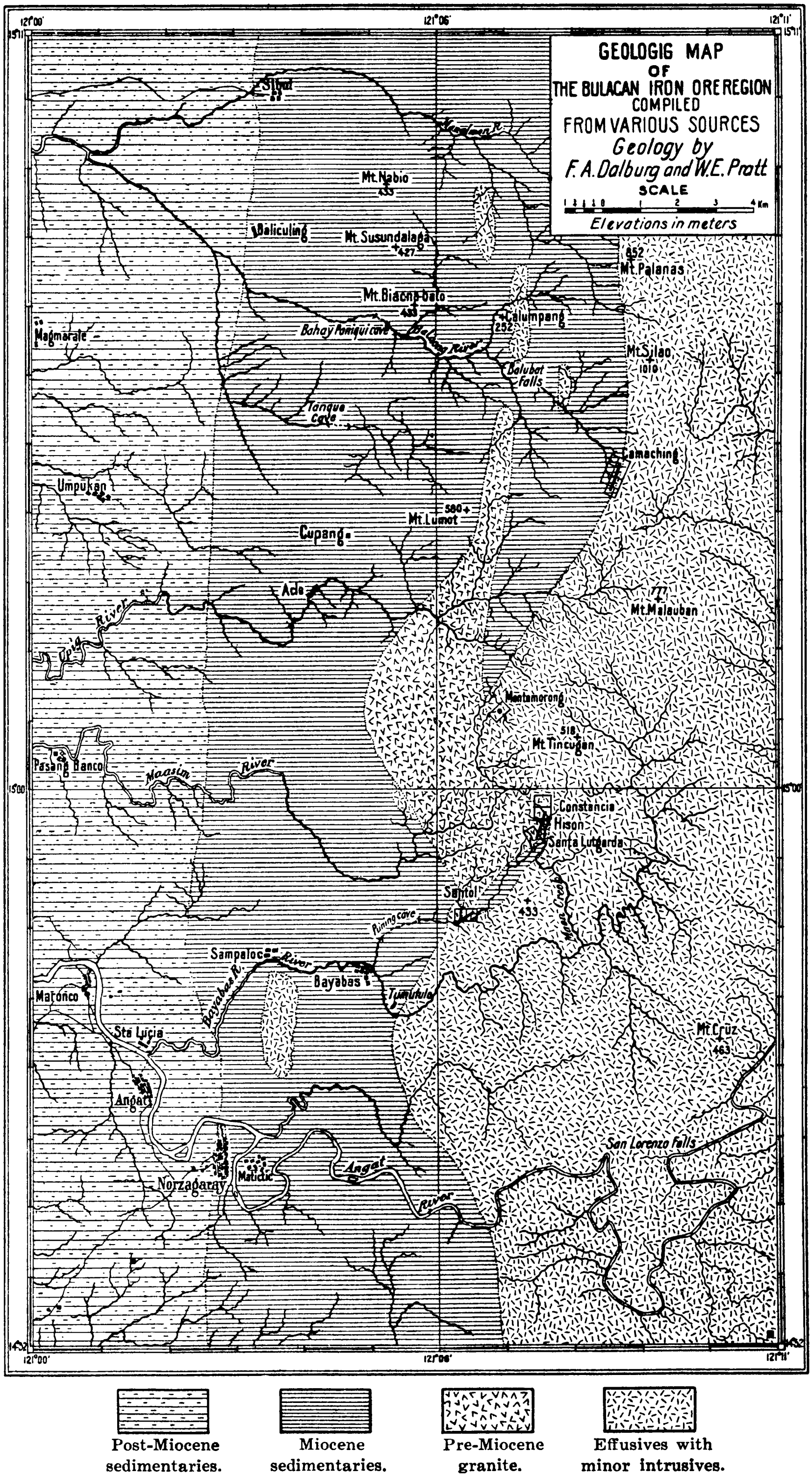
Fig. 3. Iron smelter in forest, Camaching.

PLATE V.

Fig. 1. Charcoal burning; wood in place in kiln.

Fig. 2. Charcoal burning; kiln at end of firing.

PLATE VI.


GEOLOGIG MAP
OF
THE BULACAN IRON ORE REGION
COMPILED
FROM VARIOUS SOURCES
Geology by
F. A. Dalburg and W. E. Pratt
SCALE
Elevations in meters
121°00'
121°06'
121°11'
15°11'
15°00'
14°52'
Sibul
Mt. Nabio
Baliculing
Mt. Susundalaga
Mt. Biacna-bato
Magmarale
Bahay Poniqui cave
Tanque Cave
Mt. Palanas
Calumpang
Mt. Silao
Balubat falls
Camaching
Umpukan
Cupang
Mt. Lumot
Ade
Mt. Malauban
Montemorong
Mt. Tincugan
Pasang Banco
Maasim River
Constancia
Hison
Santa Lutgarda
Santol
Sampaloc River
Bayabas
Bayabas R.
Maronco
Sta Lucia
Angat
Norzagaray
Matictic
Angat River
Mt. Cruz
San Lorenzo Falls
Post-Miocene sedimentaries.
Miocene sedimentaries.
Pre-Miocene granite.
Effusives with minor intrusives.

MICROSCOPIC STUDY OF THE BULACAN IRON ORES

By F. T. EDDINGFIELD.
(*From the Division of Mines, Bureau of Science, Manila, P. I.*)

Thin sections of ores and wall rocks of the iron deposits of Bulacan were prepared in the usual way. No attempt was made to polish the sections since the only opaques present were magnetite, hematite, pyrite, and chalcopyrite. Magnetite and hematite were differentiated by their magnetic properties and streaks, both of which were determined by tests made directly on thin sections. It was found to be very easy to obtain the streak by scratching the section with a knife point and to determine the magnetic properties by digging out a small grain with a magnetized point or knife blade.

The iron ore was found in the following forms and associations:

1. Original crystalline magnetite in quartz veins.
    (*a*) Massive.
    (*b*) Rounded, granular, in some cases with pyrite, and rarely with pyrite and chalcopyrite.
    (*c*) Crystals in needlelike and fan-shaped groups.
2. Original crystalline hematite in quartz veins.
    (*a*) In masses with needle and fan-shaped groups attached.
    (*b*) Needle and fan-shaped groups.
3. Masses of magnetite and hematite intimately mixed, usually with some pyrite, magnetite predominating.
4. Hematite granular and tabular with pyroxene, quartz, and usually with chlorite.
5. Magnetite granular and tabular with amphibole, quartz, and usually with chlorite.
6. Magnetite granular, in silicified holocrystalline igneous rock, containing pyroxene, amphibole, plagioclase, epidote, and in some cases titanite and chlorite.
7. Magnetite in small scattered grains in different rocks of all kinds found in the region.

ORIGIN OF THE ORES

There are many sources given for the origin of iron-ore deposits. Of these may be eliminated all except those relating to

magnetite and hematite. W. H. Emmons[1] gives for magnetite and hematite the following associations:

1. Igneous rocks.
2. Pegmatite veins.
3. Contact metamorphic deposits.
4. Deposits of deep vein zone.
5. Secondary minerals in zones of oxide and sulphide enrichment.
6. Products of dynamo regional metamorphosis.

It was found in examining the rock sections that by far the commonest rock carrying appreciable amounts of iron ore is a holocrystalline form, apparently a diorite. The amount of iron found in any other form of rock is so small as to be almost negligible. This association of iron ore with the holocrystalline rock leads to the conclusion that this rock has had some influence or agency in the formation of the deposits. In fact, it appears that the ore bodies resulted from contact metamorphic conditions following the intrusion of some magma contemporaneous with its cooling. The gases or solutions carrying the iron were derived from this magma upon cooling, and the iron was deposited along the contact between this magma and some other rocks, particularly a diorite, and also, as was seen in the field, along fissures in the older rocks.

The most striking feature accompanying the formation of the ore deposits is the exceedingly large amount of quartz released. Quartz is found in practically all specimens of ore and all specimens containing iron ore, and besides has replaced mineral constituents in a large portion of the rocks, making up the capping of the district. The solutions, then, contained both quartz and iron. Most of the iron was deposited first at the lowest possible levels; the quartz filled the interstices, but being in such large quantity continued upward attacking the overlying rocks and largely replacing the feldspars, giving a capping over the district of silicified rock similar to that in Baguio, where it is called the Baguio formation.

Many samples show magnetite with large amounts of pyroxene and amphibole. This class of ore is so abundant that it would appear that the pyroxene or amphibole had suffered a migration of the same character as the magnetite and quartz; that is, the solutions released from the cooling magma also contained constituents for forming these silicates. While they may have been formed by alterations of the wall rock during the deposition of the ore, the large amount formed seems to point to some other

[1] *Econom. Geol.* (1908), **3**, 620.

conditions where concentration could be more easily effected. The magnetite was the first to deposit, but at approximately the same period the pyroxene and amphibole began forming; the quartz crystallized later, filling all interstices, replacing some of the nonmetals already formed, and attacking the wall rocks and capping.

CHARACTER OF THE ORES

A most striking feature is the abundance of magnetite and apparent scarcity of hematite in the vein ores and the apparent absence of hematite in the wall rocks. In only two cases is hematite found alone as a primary mineral in the ore. In one case it occurs in vein quartz as needlelike crystals arranged generally in fan-shaped groups, and in the other case it occurs as tabular grains with pyroxene and a little quartz. On the surface are found numerous bowlders of hematite, which has led to the belief that most of the ores were hematite. These bowlders for the most part must have been the results of the oxidizing of magnetite. Hematite is also found in very small quantity mixed in with grains of magnetite in a few of the samples examined. It is apparently crystalline, but could not be identified easily.

Another prominent feature is the association of magnetite with asbestiform minerals. This class of ore is very common in the district, and is well represented in the samples examined. It comes under the head of class 5, listed on page 263, magnetite and amphibole. The asbestiform mineral appears to be the amphibole variety. It is well developed in some cases, but for the most part it represents a stage of transition and is not completely changed over to the fibrous state. The magnetite is usually granular or tabular, and exhibits a tendency for the longer axes to be parallel. The asbestiform mineral surrounds the magnetite, and has adjusted itself by bending to the shape of the magnetite.

Some specimens show augite and hematite and some hornblende and magnetite. These, too, have a general parallel arrangement of crystals.

These forms suggest pressure schistosity, but the character of the wall rock and the quartz-magnetite ore does not support this idea. It would seem that the parallelism was caused by crystallization related to the walls of the fissure, influenced by the pressure caused by the solution entering the fissure or by movement along the fissure fault. Several specimens taken from the walls of the veins have slickensides, showing that movement has taken place.

THE VEIN MINERALS

In all cases, the magnetite and crystalline hematite were the first to solidify in the deposit; a few slides show magnetite and hematite together, but so intimately associated that their relation could not be determined. Following or overlapping this period was the period of crystallization of the pyroxene and amphibole minerals, which seemed to be segregated near the walls and even to attack the walls. This was followed by the quartz period which not only filled all the crevices in the fissure but attacked the walls and, continuing upward, attacked the capping of the district.

In a few cases a pyrite period occurred accompanied by a little chalcopyrite. This came in between the iron oxide period and the quartz period.

Where magnetite or hematite is associated with quartz alone is found the beautiful treelike growth of crystals, mentioned above as needle- and fan-shaped groups. These indicate very clearly the jellylike condition of the quartz which supported the iron oxides during crystallization. These fanlike growths occur only with the quartz, and are not found with the pyroxene or amphibole or in the wall rocks. Rounded grains and masses of magnetite are also found associated with quartz, but the tabular shapes are found almost entirely in the pyroxene and amphibole portions of the deposits.

THE WALLS

The principal wall rock, according to the samples submitted, is a diorite of varying texture and crystallization. It has undergone considerable metamorphic action near the contact, being attacked principally by the iron, quartz, and to a lesser degree by the amphibole and pyroxene. It contains generally large amounts of pyroxene (or of amphibole), plagioclase, orthoclase, and quartz and frequently epidote as the chief constituents. The new minerals formed during metamorphism are magnetite, quartz, titanite, epidote, possibly zoisite and pyrite, and an added amount of amphibole or pyroxene. There appears to be no original quartz in this rock. If there ever had been, it was replaced during metamorphism.

Epidote is abundantly distributed in the andesites and diorites throughout the mineralized belt.

Titanite was probably derived from the iron ore. In one locality only, titanium is abundant in the ore, but chemical anal-

yses show small amounts to be present in most of the ores. Titanite and hairlike inclusions in the quartz which are probably rutile are found in the walls, and ilmenite is also present in several of the rocks of the district.

Chlorite is very abundant. It is almost always associated with magnetite, and is probably of secondary origin.

Magnetite is found in small quantity in practically all the silicified rock making up the capping of the district and also in the andesite and in the crystallized limestones. It is also found as small veinlets several millimeters wide in the crystallized limestones.

EDITORIAL

NOTES ON THE GEOLOGY OF PORT ARTHUR AND VICINITY

I had opportunity during a short visit to Port Arthur in September, 1913, to make the following brief notes on the geology of the surrounding portion of Liaotung Peninsula, including a part of the territory occupied by the Japanese besieging army in the course of the Russo-Japanese War.

Eliot Blackwelder [1] has already noted the topographic maturity of the land forms in Liaotung Peninsula just north of Port Arthur, as well as the drowned condition of the streams adjacent to the coast line. The main stream which empties into the bay at Port Arthur is a striking example of a submerged river. The harbor itself is formed by the former mouth of this stream, and is at present being filled with silt carried into it by this stream and one or two of its former tributaries. The country surrounding Port Arthur is made up of numerous hills of medium height, whose rounded tops show the extreme maturity of the present erosion cycle. One of the highest and most prominent is the famous 203-Meter Hill which has acquired historic interest from the struggle which attended its capture. The absolute lack of forests undoubtedly hastens the progress of erosion among these hills, and contributes to the burden of silt being deposited in the harbor. An attempt at reforestation with Scotch pine is now being made by the Japanese authorities of Port Arthur, and their effort may result in checking the process of erosion.

The dominant rock near Port Arthur appears to be a bedded quartzite, whose layers are tilted at various angles. Veins and lenses of pure quartz were observed in the quartzite. On Pumpelly's map of China [2] the lower portion of Liaotung Peninsula is colored as Devonian limestone. I saw no trace of limestone near Port Arthur, but Blackwelder [3] found metamorphic limestones or marbles associated with quartzites near Li-kuan-ts'un farther north on Liaotung Peninsula. These rocks Blackwelder refers to as the Ta-ku-shan series, and he considers them

[1] Research in China, *Pub. Carnegie Inst. Wash.* (1907), No. 54, 1, 86.

[2] Geologic researches in China, Mongolia and Japan. *Cont. Knowl., Smithsonian Inst.* (1866).

[3] *Loc. cit.*, 89.

Pre-Cambrian, rather than Devonian in age. Von Richthofen,[4] likewise, noted a similar series of metamorphic rocks at many places in Liaotung. Blackwelder records the association of conglomerate with quartzite near Li-kuan-ts'un, and I saw samples of a conglomerate composed of quartzite pebbles in the military museum at Port Arthur.

A knowledge of the geology of the region near Port Arthur might have served the officers of the Japanese army to advantage in directing their campaign in this territory. A rock composed as largely of silica as are quartzite and quartzite-conglomerate would obviously yield a very poor soil; hence, a country made up of such rocks could be expected to afford but little in the way of subsistence for an army. The hardness of the rocks in question, likewise, must have discouraged the engineers who sought to undermine forts by tunneling, especially since the necessity of keeping a knowledge of the location and progress of the tunnels from the Russians prevented the use of explosives. As a matter of fact, the average rate of advance in the tunnels was 15 centimeters per day according to the statement of a Japanese official. Yet the abundant joints and fractures in the quartzite make it much less difficult of excavation to the miner who is trained to make use of such joints (had he been secured) than to the inexperienced soldier who was probably called upon to perform the work.

WARREN D. SMITH.

[4] China, 7, 72–74 (quoted by Blackwelder).

REVIEWS

A Reader of Scientific and | Technical Spanish | for | colleges and | technical schools | with | vocabulary and notes | by | Cornelio DeWitt Willcox | Lieutenant Colonel, United States Army | [3 lines] New York | Sturgis & Walton | Company | 1913 | Cloth, pp. 1–588, $1.75.

The book is a collection of extracts from Spanish textbooks, reports, and bulletins. Although designed primarily for students of American colleges and technical schools who intend to practice the engineering profession in Spanish-speaking America, its field of usefulness extends to scientists and technical men in practice in the Philippines.

The subject matter is composed of nineteen chapters, dealing with physics, chemistry, electricity, mining, automobiles, aëronautics, submarines, etc. The book is well illustrated.

The author's good choice of materials, the variety of subjects, and the simplicity of style make the book most valuable to anyone desiring to familiarize himself with Spanish technical terms.

T. DAR JUAN.

E. Merck's | Annual Report | of recent advances in | pharmaceutical chemistry | and therapeutics 1912 | volume XXVI | E. Merck, Chemical Works, Darmstadt | 1913. Paper, pp. 1–524; Supplement, i-xix.

This valuable pamphlet treats of the recent work with about 264 preparations, and gives references to the literature.

The edition is limited, and is distributed principally among teachers of materia medica and therapeutics and among medical and pharmaceutical libraries. Generally, however, a few copies of each issue are left over after this special distribution, and physicians and pharmacists who make early application can obtain copies by remitting the forwarding charges of fifteen cents in stamps—no charge being made for the volume itself.

H. D. G.

THE PHILIPPINE

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A. CHEMICAL AND GEOLOGICAL SCIENCES
AND THE INDUSTRIES

VOL. IX | JULY, 1914 | NO. 4

WATER SUPPLIES IN THE PHILIPPINE ISLANDS

By ALVIN J. COX, GEORGE W. HEISE, and V. Q. GANA
(From the Laboratory of General, Inorganic, and Physical Chemistry, Bureau of Science, Manila, P. I.)

Five plates

WATER FOR DOMESTIC PURPOSES

Previous to the American occupation of the Philippines, no consistent or successful effort had been made to carry on a systematic study of Philippine water supplies or to improve the quality of the water used for drinking purposes. With the possible exception of a small percentage, the eight million inhabitants of the Archipelago were dependent for their drinking water upon surface supplies, shallow dug wells, open springs, or water courses. The water from the shallow wells was especially dangerous for drinking purposes on account of the common practice of washing clothes around the wells, so that water containing disease germs frequently filtered into them. One well was often used by a whole village, and the result of such conditions during a cholera epidemic can readily be imagined. During the rainy season some of the more enterprising inhabitants improved their water supply by collecting rain water in cisterns, which, however, in many cases furnished excellent breeding places for mosquitoes. A number of springs of good quality, including hot and sulphur springs having reputations for curative properties, were known and used. There was probably not an artesian well in the Islands. The relation between water supply and public health was seldom considered.

The Director of Health has said:[1]

With a few exceptions, the towns throughout the Islands are compelled to get their water from small rivers, springs, wells, irrigation canals, rain water, and any other source where water can be obtained; the rivers usually have towns on both banks for almost their entire length, and as the only system of sewage disposal is the ever-present pig or fly, the majority of the sewage is carried into the river by the first rain, if it has not already been thrown or deposited there by the people themselves.

Springs are never protected, wells are never covered; rain water collected from nipa roofs is not clean and soon becomes filled with mosquito larvæ and other insect life.

The only public water supply installation was at Manila, which derived its water from an often dangerously polluted source. Few Filipinos were free from intestinal parasites, and epidemics of water-borne diseases were prevalent.

After the American occupation, strict precautions were taken to safeguard the existing water supplies from pollution and new sources of supply were developed. It was apparent that surface water, as a general rule, was not safe for drinking purposes and that it was extremely hard to safeguard it against contamination. Hence, a special effort was made to obtain artesian wells in sufficient numbers to insure an adequate supply of potable water throughout the provinces. The Insular Government appropriated money for this purpose from time to time. The first artesian well was drilled in 1906, and since that time nearly one thousand more have been drilled by the Bureau of Public Works. Other wells have been sunk by private capital. Further to stimulate the drilling of wells, the Insular Government minimizes the cost to communities and private individuals, as shown by Act 2264 of the Philippine Legislature, which provides

for drilling artesian wells, for the construction of water supply systems, and for the construction of cisterns where artesian wells cannot be sunk, whenever the provincial boards or municipalities interested shall adopt resolutions for the appropriation of funds covering the cost of one-third of the work, one hundred thousand pesos:[2] *Provided,* That the Director of Public Works is hereby authorized to drill wells for private individuals upon the payment of one-third of the cost of the work, on condition that the public be allowed the use of the well: *Provided, also,* That from January first to July first, nineteen hundred and thirteen, in case of failure, when potable water is not found, the provincial board or the municipality shall not be obliged to pay part of the expense occasioned: *And provided further,* That the benefits of this Act shall apply to the special provinces of Mindoro, Palawan, and Batanes.

[1] *Annual Rep. P. I. Bur. Hlth.* (1906), 57.

[2] One peso (100 centavos) Philippine currency equals 50 cents United States currency.

The Bureau of Health has noted most remarkable improvement in general health conditions in localities where the use of artesian water has become general. In some places the death rate has dropped as much as 50 per cent.[3]

Another step in the improvement of water supplies for large communities consists in the reservation of uninhabited watersheds from settlement and guarding them against trespass. Watersheds at Manila and Cebu were developed, in 1908 and 1912, respectively, into sources of fairly potable water, and the good effect on the health of the people has been marked. Other similar installations are contemplated in various localities in the Islands.

A large modern Government ice plant at Manila daily produces 100,000 pounds of ice and 5,000 gallons of distilled water, which are sold to the public at reasonable prices. A new sewer system for the city of Manila, constructed at a cost of about 4,000,000 pesos, was completed in 1909.

The problem of obtaining an adequate supply of potable water is peculiarly complex in the Archipelago. The surface water, especially in inhabited districts, is unfit to drink; the high humidity and temperature stimulate decay and bacterial activity, and the general ignorance of the rules of sanitation greatly increases the difficulty of keeping such water unpolluted.

The seasons[4] in certain parts of the Islands are responsible for considerable variations in the quality of water. During the dry season the land becomes parched and dry and the water courses dwindle to a minimum; then come the heavy rains, washing the surface débris into the streams, thus polluting the water. It is estimated that in the rainy season 90 per cent of the precipitated moisture finds its way into the run-off, whereas in a shower in the dry season over 90 per cent of the water is absorbed by the soil or is directly evaporated.

In this preliminary paper on Philippine water supplies we have attempted to classify and arrange the information collected by the Bureau of Science, to draw such conclusions as may be possible, and to pave the way for future work. In spite of the large number of routine analyses performed during the last twelve years, the data at hand are incomplete. Systematic hydrographic surveys have not been made, due to the lack of

[3] *Annual Rep. P. I. Bur. Hlth.* (1907–8), 25.

[4] In a large part of the Archipelago, including Manila, most of the rains occur between June and November. In the remaining part, the rainfall is distributed throughout the year. For a discussion of the rainfall in the Philippines, and tables showing its distribution by months, see Cox, *This Journal, Sec. A* (1911), 6, 289.

funds available for such work. Most of the analyses were made at the request of other bureaus or private individuals, and we were unable to get information concerning the source or history of the sample submitted other than that given in the tables. When this work was begun, requests for water analyses were received in such number that the laboratory found itself overwhelmed with work. Only the most necessary analyses could be completed, and many determinations, especially of mineral constituents, were neglected. As transportation facilities in many parts of the Archipelago are poor, and certain samples were from twenty to thirty days old when received at the laboratory, the analyses, in many respects, cannot be said to represent accurately the composition of the original source. The number of analyses made by the Bureau of Science has increased from year to year, and at the end of the calendar year 1913 was as follows: Sanitary analyses, 750; technical analyses, 352; mineral analyses, 93.

WATER COURSES

Table I shows typical analyses of water from rivers and flowing streams throughout the Philippine Islands.

TABLE I.—*Sanitary analyses of water from rivers and flowing streams.*

[T=trace; L=little; N=nil.]

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
1	84437	November, 1910	Batangas, Pansipit River	Sample 2	Slight brown color	Alkaline.
2	84438	do	do	Sample 3	do	Do.
3	84439	do	do	Sample 4	do	Do.
4	84440	do	do	Sample 5	do	Do.
5	84441	do	do	Sample 6	do	Do.
6	98796	March, 1912	Benguet, Baguio	Pakdal Stream, Teachers Camp		
7	97173	February, 1912	Bulacan, Sibul	Estero of Sibul		Slightly alkaline.
8	97174	do	do	Estero of Sibul (No. 2)	Normal	Do.
9	77459	March, 1910	Cebu, Cebu	Lebangon River	do	Do.
10	94003	November, 1911	Cebu, proposed military reservation.	Lajog Creek [a]		Alkaline.
11	94003	do	do	do. [b]		Do.
12	94003	do	do	do. [c]		Do.
13	94003	do	do	Guadalupe Creek [d]		Do.
14	107295	September, 1912	Cebu, Buhisan	Osmeña waterworks (1)	Brownish color	Do.
15	107295	do	do	Osmeña waterworks (2)	do	Do.
16	59353	July, 1908	Iloilo	Jaro River		Do.
17	68657	May, 1909	Iloilo	Pototan River		Do.
18	68659	do	do	Jaro River		Do.
19	6851	December, 1903	Manila	City supply	Very turbid	Neutral.
20	6852	do	do	do	do	Do.
21	7063	January, 1904	do	do	Slightly turbid; slight sediment	Do.
22	7064	do	do	do	do	Do.
23	7065	do	do	do	Distinctly turbid: considerable sediment.	Do.
24	7217	do	do	do	Slightly turbid; slight sediment	

NOTE.—Footnotes follow at the end of the table, p. 282.

TABLE I.—*Sanitary analyses of water from rivers and flowing streams*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
25	7344	January, 1904	Manila	City supply	Slightly turbid; slight sediment	Neutral.
26	7592	February, 1904	do	do	Clear	
27	7721	do	do	do	do	
28	7940	do	Manila, Deposito	do		
29	8071	do	Manila, Santolan	do		
30	8374	March, 1904	Manila	do		
31	8701	do	do	do		
32	9403	April, 1904	do	do		
33	9865	May, 1904	do	do		
34	10158	do	do	do		
35	10537	June, 1904	do	do	Turbid; slight sediment	
36	10752	do	do	do		
37	11115	July, 1904	do	do	Very turbid	
38	11288	do	do	do	do	
39	69368	July, 1909	do	City reservoir No. 1, surface	Slightly turbid, brown	
40	69368	do	do	No. 2, at 3 meters' depth	do	
41	69368	do	do	No. 3, at 6 meters' depth	do	
42	69368	do	do	No. 4, inflowing water	Somewhat turbid	
43	95187	December, 1911	Oriental Negros, Dumaguete	Surface, Maite River	Clear, odorless; normal taste	Do.
44	95188	do	do	Bottom, Maite River	do	Do.
45	95189	do	do	Side surface, Maite River	do	Do.
46	95194	do	do	Surface, Dumaguete River	Turbid with disagreeable smell	Do.
47	95195	do	do	Bottom, Dumaguete River	do	Do.
48	95196	do	do	Side surface, Dumaguete River	do	Do.
49	93283	October, 1911	Palawan, Culion	Mountain stream	Normal	Do.
50	111038	January, 1913	Palawan, St. Paul Bay	Underground river		
51	88271	June, 1911	Pangasinan, Camp Agno Gorge	River Agno	Turbid; slightly brownish; clayey sediment.	Slightly alkaline.

52	3323	June, 1903	Rizal	Mariquina River		Neutral.
53	8315	March, 1904	do	Mariquina River (sample 1)		
54	8315	do	do	Mariquina River (sample 2)		
55	8315	do	do	Mariquina River (sample 3)		
56	8315	do	do	Mariquina River (sample 4)		
57	102297	May, 1912	Rizal, Santa Inez	River water	Normal	Alkaline.
58	22195	September, 1905	Samar, Laquilocan	Stream near		
59	60635	September, 1908	Samar, Catbalogan	Tibac Creek	Slightly brownish	Do.
60	60636	do	do	Palo River	Yellowish color; reddish sediment	Do.
61	19608	August, 1905	Tayabas, Tayabas	Alitaw River		
62	19608	do	do	Bamban Grande River		
63	19608	do	do	Munting Bayan River		
64	104553	July, 1912	Unknown, Winay Gulch Creek	Creek water	Normal	Do.
65	104553	do	Unknown, Galiano River	River water	do	Do.

TABLE I.—*Sanitary analyses of water from rivers and flowing streams*—Continued.

[T=trace; L=little; N=nil.]

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
1	84437	691.6	664.4	27.2	0.007	0.049	3.043	0.003	114.28	----------	----------	Pansipit River drains Taal Lake.
2	84438	718.4	694.8	23.6	0.014	0.014	1.778	L	130.54	----------	----------	Do.
3	84439	774.8	747.6	27.2	0.058	0.106	1.543	T	151.72	----------	----------	Do.
4	84440	693.6	680.4	13.2	0.002	0.021	1.350	N	130.04	----------	----------	Do.
5	84441	1463.2	1432.8	30.4	0.053	0.212	N	0.001	616.74	----------	----------	Do.
6	98796	92.0	79.0	13.0	0.053	0.14	N	N	T	----------	----------	Little blackening.
7	97173	301.2	284.1	17.1	N	0.025	0.004	N	16.71	46.5	187.1	White.
8	97174	413.2	390.9	22.3	0.013	0.024	0.02	0.024	34.40	48.3	194.8	Do.
9	77459	326.8	318.4	8.4	0.034	0.050	T	T	2.704	31.29	214.18	Little blackening.
10	94003	218.5	168.7	49.8	0.019	0.147	0.036	T	6.4	N	N	
11	94003	209.0	160.0	49.0	0.019	0.131	0.071	T	22.5	N	179.6	
12	94003	175.3	121.6	53.7	0.039	0.175	0.200	T	7.32	N	202.00	
13	94003	245.0	172.7	72.3	0.045	0.133	0.055	T	12.6	N	201.90	
14	107295	282.0	250.0	32.2	0.084	0.163	T	N	2.4	----------	----------	Blackening.
15	107295	286.8	261.4	25.4	0.036	0.115	T	N	2.4	----------	----------	Do.
16	59353	320.0	309.2	10.8	----------	----------	----------	----------	----------	N	174.00	
17	68657	304.4	295.6	8.8	----------	----------	----------	----------	----------	1.05	188.80	
18	68659	317.6	309.2	8.4	----------	----------	----------	----------	----------	N	155.50	
19	6851	220	190	30	0.008	0.078	0.15	----------	2.13	85.7		No blackening nor odor.
20	6852	181	148	33	0.005	0.073	0.271	N	2.23	85.7		Do.
21	7063	191	160	31	0.002	0.034	0.08	N	3.00	101.5		Do.
22	7064	188	142	46	0.008	0.062	0.112	----------	2.4	94.3		Do.
23	7065	188	152	36	----------	0.031	0.10	----------	2.6	90.0		
24	7217	179	148	31	0.006	0.038	0.11	----------	3.04	94.3		Do.
25	7344	176	152	24	0.002	0.044	0.198	----------	3.00	87.1		Do.

26	7592	162	142	20	T	0.048	0.10	T	2.60	104		No apparent change nor odor.
27	7721	168	152	16	0.002	0.044	0.138	N	3.20	95.0		No change in appearance and practically no odor.
28	7940	168	145	23	0.006	0.052	0.274	N	3.30	109		
29	8071	164	138	26	0.028	0.086	0.292	N	3.40	96		
30	8374	167	138	29	T	0.048	0.22	T	3.88	95		
31	8701	173	147	26	T	0.052	0.22	T	4.14	101.8		
32	9403	165	136	29	T	0.048	0.20	T	4.40	95.0		
33	9865	180	145	35	0.004	0.064	0.158	T	4.20	98.0		
34	10158	169	135	34	T	0.042	0.12	T	4.40	92.0		
35	10537	196	150	46	T	0.074	0.36	T	4.20	91.0		Slight odor and blackening.
36	10752	174	138	36	T	0.040		N	3.60	83.0		Do.
37	11115	178.0	150.0	28.0	T	0.050	0.36	N	2.80	71.4		Sample taken at time of heavy rains.
38	11288	191	159	32	T	0.068	0.22	N	3.16	58.8		Slight odor and darkening.
39	69368	156.0	128.0	28.0	0.120	0.128	0.020	N	3.23	N	76.0	Little blackening.
40	69368	157.6	119.2	38.4	0.125	0.084	T	0.001	3.03	N	89.0	Do.
41	69368	170.4	140.0	30.4	0.113	0.089	0.005	0.001	2.83	N	92.0	Do.
42	69368	156.8	124.8	32.0	0.084	0.060	0.0678	0.002	2.52	N	94.0	Do.
43	95187	222.0	205.5	16.5	0.019	0.009	T	T	6.04			White on ignition.[c]
44	95188	218.5	199.0	19.5	T	T	T	T	11.35			Do.[e]
45	95189	222.0	199.5	22.5	0.024	0.074	T	T	11.28			Do.[h]
46	95194	157.0	131.0	26.0	0.024	0.188	T	T	8.43			White.[f]
47	95195	221.5	118.5	103.0	0.049	0.224	T	T	12.85			Do.[f]
48	95196	165.0	134.0	31.0	0.024	0.099	T	T	7.15			Do.
49	93283	47.0	41.4	5.6	0.007	0.029	N	N	2.02			
50	111038				0.072	0.308	L	N	High			
51	88271	209.8	207.4	2.4	0.005	0.050	0.046	N	11.76			Slight blackening.
52	3323	179.8	139.3	40.5	0.15		8.00	N	10.8			Blackening.
53	8315	160	134	26	0.036	0.100	0.124	N	3.60	97.0		Sample taken in gorge at proposed dam site.
54	8315	153	127	26	0.021	0.080	0.139	N	3.20	93.2		Sample taken below Montalban.
55	8315	174	147	27	0.028	0.062	0.112	T	3.60	93.2		Sample taken below San Mateo.
56	8315	173	145	28	0.024	0.060	0.136	N	3.60	94.8		Sample taken at intake at Santolan.

NOTE.—Footnotes follow at the end of the table, p. 282.

TABLE I.—*Sanitary analyses of water from rivers and flowing streams*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	Chlorine.	Hardness. Permanent.	Temporary.	Behavior of residue on ignition, and remarks.
57	102297	192.2	171.0	21.2	0.067	0.094	L	T	(g)	----------	----------	Slight browning.
58	22195	288.0	196.0	92.0	0.012	----------	----------	----------	8.50	----------	----------	Blackening.
59	60635	239.6	209.2	30.4	0.010	0.081	0.257	N	3.36	----------	----------	Little blackening.
60	60636	127.6	96.4	31.2	0.133	0.253	0.097	N	4.95	----------	----------	Blackening.
61	19608	160	80	80	0.014	0.880	0.64	L	T	----------	----------	Blackening.[h]
62	19608	154	82	72	0.840	----------	1.16	N	T	----------	----------	Do.[h]
63	19608	372	280	92	0.030	0.044	0.27	N	58	----------	----------	
64	104553	164.6	163.4	1.2	0.019	0.082	L	0.01	T	----------	----------	Little blackening.
65	104553	155.6	----------	L	0.019	0.089	L	T	T	----------	----------	

[a] At high falls.
[b] At small falls 1 kilometer above high falls.
[c] One kilometer above small falls.
[d] About 4 kilometers west of the town of Guadalupe and just below confluence of its two branches.
[e] No arsenic nor other heavy metals are present.
[f] Sample received in bottle with cork stopper which smelled of vino. Some of the ammonia might have come from the stopper and contents.
[g] Sample too small for chlorine determination.
[h] Contaminated with considerable organic matter and badly discolored.

Although usually undesirable sources of water supply, rivers are necessarily used in some parts of the Philippines, especially in districts where an abundant supply of good artesian water is not available. The Manila and Cebu water-supply installations are the best examples of this type.

Some of the results shown in Table I have already been discussed by Bliss,[5] who pointed out that the variations in seasons appear to have surprisngly little effect on the chemical constituents of surface water. The bacterial count often shows enormous increase after a heavy shower. The amount of insoluble suspended matter increases appreciably in rainy weather, and the oxygen-consuming capacity appears to do the same.

Table II shows the daily variation in bacteria count, as measured in the Manila water supply, and demonstrates that water from surface streams, no matter how well guarded, is not entirely satisfactory, since it is always subject to sudden contamination.

TABLE II.—*Bacteriological examinations of the city of Manila water supply.*

Date.	Colonies.	Presumptive test.	*Bacillus coli.*	Amœbæ.	Ciliates.	Flagellates.
1913.						
Apr. 12	258	—	—	+	+	+
13	216	+	—	+	+	+
14	356	+	—	+	+	+
15	256	+	—	+	+	+
16	1,908	+	—	+	+	+
17	2,289	+	—	+	+	+
18	1,145	+	(a)	+	+	+
19	928	+	—	+	+	+
20	1,654	+	—	+	+	+
21	3,053	+	—	+	+	+
22	768	+	—	+	+	+
23	1,040	+	—	+	+	+
24	800	+	—	+	+	+
25	763	+	—	+	+	+
26	780	+	—	+	+	+
27	976	+	—	+	+	+
28	941	+	—	+	+	+
29	1,145	+	—	+	+	+
30	1,908	+	—	+	+	+
May 1	1,152	+	—	+	+	+
2	608	+	—	+	+	+
3	656	—	—	+	+	+
4	422	—	—	+	+	+
5	381	—	—	—	+	+
6	464	+	—	+	+	+

[a] *Bacillus coli* group.

[5] *Pub. P. I. Bur. Govt. Lab.* (1905), No. 20, 39.

TABLE II.—*Bacteriological examinations of the city of Manila water supply*—Continued.

Date.	Colonies.	Presumptive test.	*Bacillus coli.*	Amœbæ.	Ciliates.	Flagellates.
1913.						
May 7	254	+	—	+	+	+
8	496	+	([a])	+	+	+
9	336	+	—	+	+	+
10	906	+	—	+	+	+
11	400	+	—	+	+	+
12	656	+	—	+	+	+
15	1,399	+	—	+	+	+
16	399	+	—	+	+	+
17	416	+	—	+	+	+
18	628	+	—	+	+	+
19	1,781	+	—	+	+	+
20	1,653	+	—	+	+	+
21	2,925	+	—	+	+	+
22	3,562	+	—	+	+	+

[a] *Bacillus coli* group present.

As the density of population increases and uninhabited watersheds become scarcer, the problem of proper protection of water sources grows more complex, and measures have to be taken further to purify the water. At the present time the need of filtration and sterilization is manifest in Manila. A study to determine the method of purification best adapted to conditions in the Philippines is in progress.

Water supply in Manila.—During the Spanish régime an elaborate water-supply system was installed at Manila. A dam was built across Mariquina River, and the water was pumped from this dam to an underground reservoir having a capacity of about 72,000 cubic meters (19,000,000 U. S. gallons) and was then conducted into the city mains. The water was not filtered or otherwise purified. Mariquina River drained a territory inhabited by approximately 15,000 people, who used the river for bathing, washing clothes, depositing garbage and excreta, as well as for drinking purposes. The banks of the river were thickly inhabited, and the water passed through two large towns and a number of smaller ones. A source of this kind could never be safe. During cholera epidemics, armed guards were stationed along the river banks to protect the river as much as possible from contamination.

In 1908 a new water system was installed, deriving its supply from Mariquina River at a point above which no people live. A large dam was constructed at Montalban Gorge, and the watershed from which Mariquina River obtains its water supply

was reserved from settlement and guarded against trespassing. From this dam the water is allowed to flow through pipes to a large open reservoir having a capacity of 206,000 cubic meters (54,500,000 U. S. gallons) and to a small reserve reservoir having a capacity of 68,130 cubic meters (18,000,000 U. S. gallons). This installation furnishes an adequate supply of water for the city for almost the entire year, though in case of a long-continued dry season it is sometimes necessary to use the old intake to supplement this supply. At such times, guards are stationed along Mariquina River to prevent pollution of the stream. Though the water supplied to the city is not absolutely safe, it is an improvement over that of the old source, as is shown by health conditions.

The city of Manila has about 225,000 inhabitants, and uses approximately 48,000 cubic meters (12,700,000 U. S. gallons) of water per day. The daily per capita consumption is about 214 liters (56.5 U. S. gallons) as compared with a weighted average of 378.5 liters (100 U. S. gallons) per capita for representative American cities.[6] Water is delivered free at public hydrants, from which many of the Filipinos carry it, generally in open 5-gallon kerosene cans, to their homes, where it is often kept in ollas.

At the present time the water is unfiltered, but it is treated with enough chloride of lime before entering the city mains to correspond to an addition of 1 part of "available chlorine" in 2,000,000 parts of water. The chlorination has not appreciably lowered the bacterial count in the tap water, probably, because of the large amount of suspended organic matter. The water almost always contains amœbæ, ciliates, and flagellates, but until very recently organisms of the *Bacillus coli* group were rarely present.

Cebu water supply.—At Cebu a dam capable of impounding 1,260,000 cubic meters (333,000,000 U. S. gallons) of water from an uninhabited watershed has been constructed. In addition, a distributing system has been installed. The new waterworks were completed early in 1912.

SURFACE WELLS

It is difficult at best to get pure water from a surface well, and more difficult to keep the supply pure and unpolluted. E. Bartow[7] reports that 2,638, or 43 per cent, of 5,587 shallow wells

[6] Johnson, *U. S. Geol. Surv., Water-Supply Paper* (1913), 315, 17. See also, Salt, *This Journal, Sec. D* (1913), 8, 165.

[7] *Ind. San. and W. S. A.* (1913), 86–90.

examined in Illinois from 1907 to 1912 were condemned. H. E. Barnard[8] states that an examination of 5,000 wells in Indiana showed over 50 per cent to be polluted, and he recommends the abandonment of every surface well in the State. When such is the opinion expressed in the United States, the general undesirability of surface wells in the Philippines must at once be apparent. Here we must contend with the effect of higher humidity and temperature, increased bacterial activity, rapid putrefaction, and the ignorance of many of the inhabitants with regard to the necessity of pure water. A simple hole in the ground, unlined and without a curb, covered partially with a loose bamboo platform, has frequently been considered an adequate and satisfactory installation. Such a well, situated in the midst of a crowded barrio where life is conducted in a primitive manner and where there are no sewerage facilities, cannot possibly be
and where there are no sewerage facilities, cannot possibly be
safe. Practically every shallow well examined by the Bureau of Science has been found dangerously polluted. The analyses given in Table III are typical.

[8] *Ibid.* (1913), 43–46.

TABLE III.—*Sanitary analyses of water from surface wells.*

[L=little; N=nil; T=trace; E=present.]

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
1	86655	February, 1911	Bohol, Luncayab, Tagbilaran.	Surface well		Alkaline.
2	86656	do	Bohol, Mansasa, Tagbilaran.	do		Do.
3	117073	September, 1913	Cebu, Engayo	Dug well, 7.6 meters deep [a]	Normal	Neutral.
4	117477	October, 1913	Cebu, Cebu	Dug well, 24 meters deep, near Southern Island Hospital.	do	Alkaline.
5	38586	December, 1906	Ilocos Sur, Vigan	Municipal well, 34 meters deep		
6	38588	do	do	Well, north part of city		
7	38589	do	do	Provincial government well		
8	38592	do	do	"Camarin" well, 2 meters deep		
9	93063	October, 1911	Laguna, Biñan	Open well at back part of cockpit, north part of town.	do	
10	93063	do	do	Ordinary open well in center of town.	do	Do.
11	27849	February, 1906	Manila, Calle Anda 131			
12	31337	June, 1906	Manila, Intramuros	"Fundition 99"		
13	93109	October, 1911	Manila, Observatory	Sample I, open well	Brownish color with dark, flaky sediment.	Do.
14	93109	do	do	Sample II, open well	Yellow color, small amount of sediment.	
15	92027	September, 1911	Mindoro, San Jose			
16	114362	June, 1913	Nueva Ecija, Cabanatuan, Plainfield.	Well 10 meters deep; water at 8.5 meters.	Normal	Do.

NOTE.—Footnotes follow on p. 288.

TABLE III.—*Sanitary analyses of water from surface wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
17	1067	February, 1903	Pangasinan, Camp Gregg			Alkaline.
18	Sample I	October, 1911	Rizal, Pasay		Normal	Do.
19	Sample II	do	do	Open well[c]	Brownish color	Do.
20	Sample III	do	do	do[d]	do	Do.
21	117023	September, 1913	Rizal, Morong	No. 546; 27 meters deep; pumps 133 liters per minute, water at 1.5 meters.		
22	117944	December, 1913	Tayabas, Lucena	Barrio of poblacion; surface well 11 meters deep.	Normal	Do.
23	76846	March, 1910	Tayabas, Malanay	Sample I; surface water	do	Slightly alkaline.
24	76846	do	do	Sample II; surface water	do	Do.
25	76846	do	do	Sample III; surface water	do	Do.

[a] Well 10 meters from a large ditch serving as street drain.
[b] Approximate.
[c] Calle Burgos, Pasay, near the artesian well in front of municipal school.
[d] No. 3, Calle Domingo, Pasay (half-way between the last two mentioned above).

TABLE III.—*Sanitary analyses of water from surface wells*—Continued.

[L=little; N=nil; T=trace; E=present.]

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as—				Chlorine.	Hardness.		Behavior of residue on ignition, and remarks.
					Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		Permanent.	Temporary.	
1	86655	396.2	391.2	5.0	0.005	0.121	T	0.040	52.88			Blackening.
2	86656	1,220.0	1,167.0	53.0	0.012	0.080	1.919	N	436.54			
3	117073	456.4			0.014	0.002	L	T	26.71			*B. coli* present.
4	117477	405.6			0.019	0.019	E	N	5.88			
5	38586	324.6	292.6	32.0	0.006	0.044	0.363		28.04			
6	38588	164.0	128.0	36.0	0.014	0.202	1.394		15.26			Blackening.
7	38589	869.6	767.2	102.4	0.041	0.237	29.180		104.72			Slight blackening.
8	38592	213.0	200.2	13.2	0.015	0.042	0.384	T	13.91			
9	93063	530.4	506.6	23.8	0.026	0.031	3.643	0.005	78.22			
10	93063	810.6	769.8	40.8	0.012	0.017	21.480	0.007	89.11			
11	27849	1,228.0		172.0	0.11	0.41			308.00			
12	31337	470.0	376.0	94.0	0.38	0.192			71.8			Contains small amounts of hydrogen sulphide and sulphur dioxide.
13	93109				0.246	0.162	[b]1.00	[b]0.002	377.0	67.1	499.5	
14	93109				0.640	0.422	[b]4.00	[b]0.005	20.6	24.6	87.0	
15	92027				0.012	0.014	T	T	5.47			
16	114362	248.0	220.0	28.0	0.019	0.012	N	N				Blackening.
17	1062	1,024.0		270.0			T	E				
18	Sample I	890.0	825.0	65.5	0.054	0.120	4.953	0.009	131.68			Slight browning.
19	Sample II	1,192.7	1,120.5	72.2	0.038	0.207	0.092	T	137.62			Do
20	Sample III	787.7	725.2	62.5	0.053	0.169	13.398	0.082	89.11			Do.
21	117023	888.8			0.137	0.048	11.17	0.4	144.1			*B. coli* present.
22	117944	530.0			0.009	0.043	T	N	26.84			Do.
23	76846	499.0	475.4	23.6	0.014	0.038	T	N	28.45			
24	76846	496.4	484.4	12.0	0.075	0.652	T	N	17.73			Slight blackening.
25	76846	556.8	542.4	14.4	0.007	0.070	T	N	43.71			Do.

SPRINGS

There are large numbers of springs in the Philippines, many of which are credited with medicinal properties. Thermal springs are numerous, and there are many springs which are heavily charged with gases or with mineral salts. These are discussed under a separate head on page 381. Sanitary analyses of Philippine springs are given in Table IV.

TABLE IV.—*Sanitary analyses of spring waters.*

[C=considerable; E=excessive; H=high; L=little; N=nil; P=present; T=trace.]

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
1		October, 1911	Abra, Comillas crossing, Abra River.	Hot spring	Brackish	
2	115731	August, 1913	Albay, Tiwi	Tiwi Springs	Normal	Acid.
3	114838	June, 1913	do	Hot spring	Brown with clay sediment, turbid	Do.
4	115071	June, 1913	Ambos Camarines, Lanot Spring.		Turbid and brownish yellow	Do.
5	115732	August, 1913	Batangas, Gapas, Balayan			Alkaline.
6	788	September, 1902	Benguet	Sanitarium spring	Very small amount of sediment	
7	789	do	do	Bued River Spring	do	
8	790	do	do	Loo Spring	do	
9	1006a	October, 1902	Benguet, Twin Peaks	South Spring, cold	Clear, cold, and tasteless	Do.
10	1006b	do	Benguet, Bued River	Hot spring above river	Clear; taste and odor of sulphur; temperature 75° C.	Do.
11	1006c	do	Benguet, Twin Peaks	Stream in gorge	Cold and tasteless	Do.
12	1006d	do	do	North Spring	Cold, tasteless, and odorless	Do.
13	1006e	November, 1902	do	Small spring 4.8 kilometers above.	Clear and odorless	Do.
14	1006f	do	do	Sample taken from stream	Tasteless and odorless	Do.
15	1006g	do	do	Hot spring on right bank of river.	Taste and odor of sulphur; temperature 93° C.	Do.
16	1006h	do	Benguet	Right bank opposite Camp 5	Cold; blue and green deposit	Do.
17	1006i	do	do	Right bank opposite Camp 5, sample not taken from source.	Tasteless	Do.
18	1006j	do	do	Left bank, 300 meters below Camp 5.	Clear and tasteless	Do.
19	1006k	do	do	Large spring near Baguio[a]	do	Slightly acid.

NOTE.—Footnotes follow on p. 295.

TABLE IV.—*Sanitary analyses of spring waters*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
20	10061	November, 1902	Benguet, Baguio	Spring 1 kilometer east of hospital.	Tasteless and odorless	Neutral.
21	1006m	do	Benguet	Large spring, Baguio [a]	Clear and tasteless	Slightly acid.
22	27710	January, 1906	Benguet, Baguio	Main spring		
23	27711	do	do	Small spring		
24	29528	April, 1906	Benguet, Twin Peaks		Clear	
25	29597	do	Benguet, hot spring		Clear, little sediment	
26		October, 1911	Benguet, Daklan	Lower spring	Normal	Alkaline.
27	99591	May, 1912	Benguet, Camp John Hay, Baguio.	Big spring	Colorless, clear with slight astringent taste.	Acid.
28	104286	June, 1912	Benguet, Hospital Hill, Baguio	Spring at foot of landslide	Yellow, with little light sediment	Slightly acid.
29	93928	December, 1911	Bohol, Loay			Alkaline.
30	97168	February, 1912	Bohol, Tubigan			Neutral.
31	97865	March, 1912	Bohol, Duero		Normal	Alkaline.
32	104914	July, 1912	Bohol, Tubigan		do	Do.
33		October, 1911	Bontoc, foot of hill at Cervantes	Hot spring		
34	9704	May, 1904	Bulacan, Sibul, San Miguel de Mayumo.		Slight white sediment	Neutral.
35	16266	March, 1905	do			
36	38388	December, 1906	do	Sibul Springs		
37	58945	June, 1908	do	do		Alkaline.
38	99010	March, 1912	Bulacan, San Miguel de Mayumo.	do	Normal	Do.
39	101756	April, 1912	do	do	do	Do.
40	107330	September, 1912	Bulacan, Sibul Spring	do	do	
41	111407	January, 1913	do		do	Neutral.
42	9704	May, 1904	Camarines, Goa	"Lalo Lagonoy"	Turbid, slate color	Alkaline.
43	9704	do	Camarines, Pasacao	"Punta Mainit"	Clear	Neutral.

44	101757	May, 1912	Camarines, Paracale	Spring at Cabeza Reginos	Normal	Alkaline.
45	101757	do	do	Spring at Guinobatan	do	Slightly acid.
46	115229	July, 1913	Capiz, Dumalag	Spring at Sohut	do	Alkaline.
47	114039	May, 1913	Cebu, Carcar	Spring near Carcar	Contains sediment	Do.
48		October, 1910	Cebu, Mainit, Naga	North Spring	Transparent with bluish tint; smells of hydrogen sulphide, and has saline taste.	
49		do	do	South Spring	do	
50		do	Cebu, Guadalupe, Carcar	Spring at base of mountain	Clear and transparent with bluish tint; smells of sulphureted hydrogen.	
51		do	Cebu, Bolacbolac, Barili	Spring at base of hill	Colorless, with slight hepatic smell and taste.	
52		do	Cebu, Kanaga, Sibonga	North Spring	Clear and transparent with bluish tint and pronounced odor of sulphureted hydrogen.	
53		October, 1911	do	South Spring	Clear and transparent with bluish tint and odor of sulphureted hydrogen.	
54		do	Cebu, Kambangog, Toledo	Spring at base of mountain	Continuous bubbling of H_2S and CO_2.	
55		October, 1910	Cebu, Oslob	Spring A, 40 meters from sea	Clear and transparent with opaline color; has frequent gaseous bublings and odor of sulphureted hydrogen.	
56		do	do	Spring B, a few meters north of Spring A.	Clear and transparent with opaline color; has gaseous bubbling and odor of sulphureted hydrogen.	
57		do	do	Spring C, 30 meters northwest of Spring B.	Clear and transparent with opaline tint; has gaseous bubbling and slight odor of sulphureted hydrogen.	
58	51541	November, 1907	Cebu, Mandane			

NOTE.—Footnotes follow on p. 295.

TABLE IV.—*Sanitary analyses of spring waters*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Physical properties.	Reaction.
59	116421	August, 1913	Coron, Uson	Spring at coal dock	Light brown	
60	117934	December, 1913	Ilocos Sur, Danglas	Hot spring	Red brown	Neutral.
61	111156	January, 1913	Ilocos Sur, Vigan	East Naguiddayan Spring	Normal	Alkaline.
62	98446	March, 1912	do	Naguiddayan Spring	do	
63	106551	August, 1912	do	Naguiddayan West Spring	do	Do.
64	11035	July, 1904	Laguna, Pagsanjan	Bocal Spring		
65	27577	January, 1906	do			
66	97081	February, 1912	Laguna, San Pablo			Neutral.
67	108464	October, 1912	Laguna, Pagsanjan	Spring 1	Normal	Alkaline.
68	108464	do	do	Spring 2	do	Do.
69	108464	do	do	Spring 3	do	Do.
70	113260	April, 1913	Laguna, Santa Cruz	Sinabac Spring	do	Do.
71	116154	September, 1913	Misamis, Camiguin	Catarman	do	
72	115260	July, 1913	Occidental Negros, Mambucao	Medicinal spring		
73	95191	December, 1911	Oriental Negros, Dumaguete	Spring 1	Turbid; disagreeable smell	Slightly acid.
74	95192	do	do	Spring 2	do	Do.
75	95193	do	do	Spring 3	Clear, and disagreeable smell	Do.
76	113346	July, 1913	Oriental Negros, Guijulngan	Hot spring	Turbid	Alkaline.
77	117015	September, 1913	Oriental Negros, Masapalud	Mineral spring	do	Acid.
78	113345	July, 1913	Oriental Negros, Polimpinon	Hot spring	do	Alkaline.
79	93284	October, 1911	Palawan, Culion	Sample II, Balala Spring	Normal	Neutral.
80	104177	June, 1912	Palawan, Culion, Balala	No. 1	do	Acid.
81	104177	do	do	No. 2	do	Alkaline.
82	78654	June, 1910	Rizal, Antipolo	"Mabolo" Spring	do	Do.
83	78655	do	do	"Tandang-Yang" Spring	do	Do.
84	78656	do	do	"De la Virgen" Spring	do	Do.
85	78657	do	do	"Marurunong" Spring[f]	do	Do.
86	81824	September, 1910	Rizal, Malabon	St. Bartolome Street Spring		Do.

87	87713	May, 1911	Rizal, Antipolo	"Mabolo" Spring		Acid.
88	87714	do	do	"Vocal ñg Tandangyang" Spring.		Do.
89	87715	do	do	"De la Virgen" Spring		Do.
90	87716	do	do	"Marurunong" Spring		Do.
91	87717	do	do	"Visaya" Fountain		Do.
92	87718	do	do	"Tanag" Spring		
93	87719	do	do	"Lucay" Spring		Do.
94	87720	do	do	"Canda" Spring		
95	102294	May, 1912	Rizal, Mount Cailapa, Santa Inez.		Normal	Alkaline.
96	60637	September, 1908	Samar, Catbalogan	Villarmosa Hot Spring	do	Do.
97	60638	do	do	Naval Hot Spring	Taste and odor of petroleum	Do.
98	19608	August, 1905	Tayabas, Tayabas	Laurente Spring		
99	19608	do	do	Taliong Spring		
100	114194	June, 1913	Tayabas, Marinduque	Malbog Spring	Turbid	Neutral.
101	115733	July, 1913	do	Gasang Mineral Spring		

[a] Source of Bued River.

[f] Antipolo water supply.

TABLE IV.—*Sanitary analyses of spring waters*—Continued.

[C=considerable; E=excessive; H=high; L=little; N=nil; P=present; T=trace.]

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
1	......	2,021.8	1,976.2	45.6	0.231	0.067	N	N	562.18	......	......	
2	115731	180.8	......	......	0.077	0.024	N	N	4.45	......	......	
3	114838	438.0	......	......	6.267	0.217	T	N	2.47	......	......	Blackening.
4	115071	654.4	......	......	0.012	0.181	N	N	155.84	......	......	
5	115732	601.6	......	......	0.046	0.036	N	0.006	57.9	......	......	
6	788	112.0	43.6	68.4	T	......	N	......	T	......	......	Slight blackening; sharp odor.
7	789	49.3	30.0	19.3	T	......	N	......	T	......	......	Do.
8	790	685.6	560.6	125.0	T	......	N	......	T	......	......	Practically no blackening nor odor.
9	1006a	294.0	......	......	......	......	T	T	T	......	......	
10	1006b	1,556.0	......	......	......	......	N	N	460.0	......	......	Volume hydrogen sulphide, 12.1 cc. per liter; deposit sediment on rock.
11	1006c	320.0	......	......	......	......	T	T	N	......	......	Volume hydrogen sulphide, 2.07 cc. per liter.
12	1006d	271.0	......	......	......	......	T	T	N	......	......	Volume hydrogen sulphide, 4.67 cc. per liter.
13	1006e	347.0	......	......	......	......	N	N	N	......	......	Mineral (lime?) deposit; volume hydrogen sulphide, 0.96 cc. per liter.
14	1006f	341.0	......	......	......	......	T	T	N	......	......	Volume hydrogen sulphide, 7.32 cc. per liter.
15	1006g	1,447.0	......	......	......	......	N	N	1038.0	......	......	Volume hydrogen sulphide, 0.65 cc. per liter.
16	1006h	563.0	......	......	......	......	N	N	T	......	......	
17	1006i	355.0	......	......	......	......	N	N	T	......	......	Dark brown deposit; volume hydrogen sulphide, 17.4 cc. per liter.
18	1006j	417.0	......	......	......	......	N	N	N	......	......	Yellowish (lime?) deposit.

19	1006k	24.0					N	N	N			Sulphurous odor near source; volume hydrogen sulphide, 1.00 cc. per liter.
20	10061	64.0					T	T	N			
21	1006m	50.0					N	N	N			Flow, about 170 liters per second.
22	27710	51.0	33.0	18.0	0.02	0.19	N	N	5.12			Slight blackening.
23	27711	53.8	44.0	9.8	0.02	0.15	N	N	8.54			Do.
24	29528	270.0	250.0	20.0	0.06	0.12						Very slight blackening.
25	29597	1,511.2	1,466.2	46.0	0.09	0.09	N	N	555.1			Blackening.
26		311.8	304.8	7.0	0.362	0.019	T	N	53.46			Slight browning.
27	99591	62.6							T			Blackening and smell of burnt organic matter and evolution of SO_2.[b]
28	104286	306.0	105.0	201.0	0.019	0.217	L	N	2.94			(c)
29	93928	346.0	320.3	25.7	0.01	0.02	0.009	0.001	10.4	N	314.0	Proposed water supply of Loay.
30	97168	265.7	248.5	17.2	N	T	0.125	0.019	13.3			Total hardness, 166.6; white.
31	97865	249.8		L	0.012	0.026	0.149	N	4.90			
32	104914	321.0	314.0	7.0	0.014	0.081	P	T				
33					0.012	0.031	N	N	343.28			
34	9704	534.0	452.0	82.0			T		34.0			
35	16266	504.0	384.0	120.0	0.024	0.046	0.255	T	33.0			
36	38388	513.6	469.6	44.0	0.06	0.13			42.77			
37	58945	487.6	458.0	29.6	0.009	0.034	N	N	31.3			
38	99010	479.2			0.012	0.034	T	T	31.37			
39	101756	482.6			0.031	0.089	T	T	31.37			
40	107330				0.070	0.082	L	0.052	9.9			
41	111407	482.4	424.4	58.0	0.029	0.031	N	N	27.5			
42	9704	1,908.0	1,650.0	258.0	T				404.0			
43	9704	526.0	414.0	112.0	T		T	T	53.0			
44	101757	152.4			0.084	0.067	P	0.006	14.70			Little blackening.
45	101757	97.2			0.0483	0.084	T	T	13.72			Do.
46	115229	240.0			0.002	0.072	T	P	5.44			
47	114039	300.00	260.00	40.00	0.030	0.003	4.00	0.09	21.0			Projected municipal water supply.
48					0.002	0.032	T	T	116.25			
49					0.002	0.018	T	N	116.25			
50					0.229	0.059	0.591	0.552	27.09			

NOTE.—Footnotes follow at the end of the table, p. 299.

TABLE IV.—*Sanitary analyses of spring waters*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
51	------	------	------	------	0.002	0.004	T	T	17.36	------	------	High bacterial content indicates pollution.
52	------	------	------	------	0.089	0.030	N	T	25.12	------	------	
53	------	------	------	------	0.002	0.036	0.129	N	30.29	------	------	
54	------	------	------	------	0.248	0.070	T	0.009	125.12	------	------	
55	------	------	------	------	0.636	0.050	------	T	64.53	------	------	Temperature of water, 35°C.
56	------	------	------	------	0.323	0.057	T	0.165	67.24	------	------	Temperature of water, 35°.8 C.
57	------	------	------	------	0.002	0.030	0.803	T	28.69	------	------	Temperature of water, 29°.9 C.
58	51541	386.0	371.8	14.2	0.005	0.015	4.700	N	4.50	25.00	270.0	
59	116421	56.8	------	------	0.029	0.065	N	N	10.3	------	------	Contained bacilli of the *B. coli* grou
60	117934	2113.6	------	------	4.27	0.616	N	1.7	226.6	------	------	Blackening.
61	111156	270.4	257.8	12.6	0.007	0.041	0.402	N	4.75	------	------	Contains *B. coli*.[d]
62	98446	217.0	216.0	1.0	0.026	0.058	T	0.008	4.41	------	------	
63	106551	219.0	188.0	31.0	0.009	0.005	P	T	4.90	------	------	
64	11035	310.0	240.0	70.0	N	0.010	0.040	T	13.60	------	------	No odor or blackening.
65	27577	293.0	213.0	81.0	0.016	0.03	N	N	17.7	------	------	
66	97081	209.5	174.8	34.7	0.009	0.014	0.003	0.001	12.43	------	------	Total hardness, 101.3; white.
67	108464	303.8	276.0	27.8	0.029	0.019	T	N	9.85	------	------	
68	108464	301.6	306.6	N	0.029	0.0193	T	N	15.7	------	------	
69	108464	291.0	269.2	21.8	0.022	0.006	T	N	15.7	------	------	
70	113260	100.0	94.0	6.0	N	0.055	N	N	2.9	------	------	
71	116154	348.4	------	------	0.127	0.042	T	T	4.41	------	------	
72	115260	339.2	------	------	0.191	0.094	N	0.33	8.9	------	------	
73	95191	323.5	207.5	116.0	0.099	0.258	T	T	10.43	------	------	(h)
74	95192	395.0	350.0	45.0	T	0.124	T	T	21.6	------	------	(h)
75	95193	252.5	210.0	42.5	0.124	0.149	T	T	15.38	------	------	(h)
76	113346	594.8	540.0	54.8	0.007	0.053	L	L	------	------	------	

77	117015	1,586.0	....	....	0.089	0.039	N	N	....	....	....	
78	113345	6,025.2	5,707.6	317.6	0.036	0.038	2.933	N	3120.0	....	....	
79	98284	28.8	24.2	4.6	0.007	L	[e]0.5	N	0.675	....	....	
80	104177	28.6	22.8	5.8	0.031	0.077	P	T	3.90	....	....	
81	104177	79.0	67.2	11.8	0.046	0.137	L	T	7.8	....	....	
82	78654	237.6	206.4	31.2	0.004	0.022	T	L	2.78	N	120.60	Slight browning.
83	78655	232.0	202.4	29.6	0.004	0.046	0.277	0.003	2.30	N	112.00	Do.
84	78656	289.0	233.0	56.0	0.008	0.038	1.250	T	20.65	10.40	110.00	Do.
85	78657	166.6	139.6	27.0	0.062	0.028	0.079	T	1.90	N	82.60	Do.
86	81824	472.8	453.2	19.6	0.007	0.089	8.367	T	53.53	....	....	
87	87713	....	....	....	0.029	0.007	H	T	2.09	....	....	Probably surface water.
88	87714	....	....	....	0.019	0.012	H	T	2.09	....	....	Do.
89	87715	....	....	....	0.019	L	E	T	17.14	....	....	Do.
90	87716	....	....	....	0.036	0.014	E	T	1.52	....	....	Do.
91	87717	....	....	....	0.014	0.021	E	T	2.28	....	....	
92	87718	....	....	....	0.147	0.041	H	0.009	2.476	....	....	
93	87719	....	....	....	0.091	0.045	E	0.039	40.95	....	....	
94	87720	....	....	....	0.038	0.005	E	0.016	47.62	....	....	
95	102294	246.0	219.6	26.4	0.094	0.145	L	T	(g)	....	....	Slight browning.
96	60637	446.4	408.0	38.4	0.002	0.029	T	0.056	53.86	....	....	
97	60638	746.4	630.0	116.4	0.109	0.080	N	N	29.31	....	....	Slight darkening.
98	19608	120.0	88.0	32.0	0.004	0.018	0.140	C	7.00	....	....	
99	19608	102.0	74.0	28.0	N	0.046	0.120	C	7.00	....	....	
100	114194	1,138.4	1,021.6	116.8	1.195	0.253	N	T	....	....	....	
101	115733	1,180.0	....	....	1.352	0.157	N	N	110.5	....	....	

[b] The total solids are less than the sum of the ingredients on account of the volatilization of sulphuric acid (H_2SO_4) on drying the total solids at a temperature of about 200° C. One liter of sample required 7.7 centimeters N/10 NaOH to neutralize. Cannot be recommended for boiler feed water, unless previously treated.

[c] The sample was delivered in 3 Tansan bottles, had a slight wine odor, and on evaporation left a residue well charged with organic matter.

[d] Desired for municipal water supply.

[e] Approximate.

[g] Sample too small for chlorine determination.

[h] Sample received in bottle with cork stopper which smelled of vino. Brownish on ignition.

DEEP WELLS

The best natural potable water is at present furnished by artesian wells, and as has already been indicated this source is being rapidly utilized. Table V, showing the number of wells drilled by the Bureau of Public Works from year to year, indicates the manner in which the work of supplying the country with water is progressing.

TABLE V.—*Wells drilled by Bureau of Public Works.*

Year ending June 30—	Deep wells driven.	Jet-rig wells driven.	Insular expenditure.
			Dollars.
1905	2	----------	6,500
1906	3	----------	6,000
1907	12	----------	14,000
1908	9	----------	21,000
1909	12	112	55,000
1910	13	159	98,500
1911	17	199	154,400
1912	42	104	154,500
1913	92	54	186,900
1913 (July 1-Dec. 31)	55	29	121,300
Total	257	657	818,100

Table VI contains sanitary analyses of water from deep wells throughout the Philippine Islands.[9]

[9] Technical analyses of waters are included in Table VII.

TABLE VI.—*Sanitary analyses of water from deep wells.*

[E=excessive; L=little; N=nil; P=present; T=trace; U=undetermined.]

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
1	86551	March, 1911	Agusan, Butuan	No. 223	Somewhat turbid with brackish taste and brownish sediment.	
2	117705	October, 1913	Albay, Albay	No. 550; 120.4 meters deep; steel cased 85 meters; pumps 45 liters per minute.	Normal	Alkaline.
3	112669	April, 1913	Albay, Ligao	No. 494; 91.4 meters deep; flows 40 liters per minute.	do	Do.
4	118001	December, 1913	Albay, Malinao	No. 578; 114.3 meters deep; flows 170 liters per minute.	do	Do.
5	115366	July, 1913	Albay, Oas	No. 505; 152.4 meters deep; pumps 285 liters per minute.	Turbid; yellowish brown, with clayey sediment.	
6	117935	December, 1913	Bataan, Pilar	At Calle San Pedro		Neutral.
7	117935	do	do	At Calle Kansas		Do.
8	117935	do	Bataan, Santa Rosa, Pilar	At Liwasan		
9	117935	do	Bataan, Pilar	At Calle Mabolo	Turbid	Do.
10	117935	do	Bataan, Bataan Pequeño, Pilar	At Calle San Jose		
11	117935	do	Bataan, Santa Rosa, Pilar	At Calle Masantol		
12	117935	do	Bataan, Pilar	At Calle San Jose		Do.
13	117462	October, 1913	Batangas, Alitagtag	No. 507; 112.7 meters deep; water at 60 meters; pumps 190 liters per minute.	Normal	Alkaline.
14	70173	September, 1909	Batangas, Taal	No. 92; 189 meters deep	do	Do.
15	78712	July, 1910	Batangas, Balayan	No. 164; 114.3 meters deep; flows 230 liters per minute.	do	Slightly alkaline.
16	79221	do	do	No. 175; 122 meters deep; flows 570 liters per minute.	do	Alkaline.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
17	79230	October, 1910	Batangas, Batangas		Normal	Alkaline.
18	62394	November, 1908	do		do	Do.
19	68518	May, 1909	Batangas, Bauan	No. 79	do	Do.
20	117608	October, 1913	do	No. 499; 152 meters deep; cased to 125 meters; pumps 75 liters per minute.	Normal	Neutral.
21	117610	do	do	No. 522; 213.2 meters deep; cased 123.5 meters; pumps 75 liters per minute.	Turbid	Alkaline.
22	117897	December, 1913	do	No. 563; 152.7 meters deep; pumps 190 liters per minute at 12.8 meters' depth; water at 10.9 meters.	Normal	Neutral.
23	117444	September, 1913	do	No. 555; 152.4 meters deep; pumps 300 liters per minute.	Light brown	Do.
24	113010	April, 1913	do	No. 495; 90.8 meters deep; flows 380 liters per minute.	Normal	Alkaline.
25	117898	December, 1913	Batangas, Lagnas, Bauan	No. 571; pumps 760 liters per minute at 4.8 meters; water level at 3.6 meters.	do	Neutral.
26	112113	February, 1913	Batangas, Bauan	No. 495; 90.8 meters deep; flows 380 liters per minute.	do	Alkaline.
27	117463	October, 1913	Batangas, Balisong, Taal	No. 529	do	Do.
28	93292	October, 1911	Batangas, Nasugbu	No. 307; 187.4 meters deep; flows 20 liters per minute.	Yellow	Do.
29	95430	February, 1912	do	No. 339		Do.
30	98447	March, 1912	Batangas, Balayan, Calatagan	No. 354		
31	105125	July, 1912	Batangas, Lipa	No. 420		Neutral.

32	108462	October, 1912	Batangas, Tanauan	No. 436	Brownish; turbid; little sandy sediment.	Alkaline.
33	109934	December, 1912	do	No. 469	Turbid	Do.
34	115331	July, 1913	Batangas, Santo Tomas		Yellow and turbid	
35	112111	February, 1913	Benguet, Camp John Hay	77.7 meters deep; cased 40.5 meters; water at 4.5 meters.	Normal	Do.
36	115133	June, 1913	Benguet, Tagudin	No. 501; 92.6 meters deep; pumps 56 liters per minute.		
37	117402	September, 1913	do	No. 515; 192 meters deep; flows 20 liters per minute.	Normal	Do.
38	74676	December, 1909	Bohol, Dimiao		do	Do.
39	79477	July, 1910	Bohol, Ilaya, Loboc	No. 3	Slightly turbid	Do.
40	79478	do	Bohol, Loboc	No. 2	Brownish	Slightly alkaline.
41	117767	November, 1913	Bohol, Loon	No. 551; 82.3 meters deep; cased 79.2 meters; pumps 56 liters per minute.	Brown with sediment	Neutral.
42	79479	July, 1910	Bohol, Sauang, Loboc	No. 1; 170.7 meters deep; flows 227 liters per minute.	Normal	Do.
43	80289	do	Bohol, Tagbilaran	No. 167		Alkaline.
44	81901	September, 1910	Bohol, Baclayan		Normal	Neutral.
45	83330	October, 1910	Bohol, Sauang, Loboc		Turbid, with brown sediment	Do.
46	83331	do	Bohol, Villaflor, Loboc		do	Do.
47	83717	do	Bohol (Tagbilaran No. 2)	No. 192.2 meters deep; pumps 23 liters per minute.	Normal	Do.
48	83743	do	Bohol, Laya, Baclayan			Do.
49	85093	December, 1910	Bohol, Ubus, Tagbilaran			
50	85750	January, 1911	Bohol, Alburquerque			Do.
51	87828	April, 1911	do		Normal	Do.
52	88706	June, 1911	Bohol, Tagbilaran, Mansasa		Brackish	Do.
53	91226	August, 1911	do			
54	96694	February, 1912	Bohol, Panglao, Tagnan		Normal	Do.
55	42392	April, 1907	Bulacan, Malolos	Municipal well		
56	42794	do	do	Municipal well; 56.4 meters deep		

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
57	43533	May, 1907	Bulacan, Bulacan	Municipal well		
58	44052	do	Bulacan, Guiguinto			
59	46442	July, 1907	Bulacan, Bigaa	92 meters deep; flows 8 liters per minute.		
60	47956	August, 1907	do			
61	47957	do	Bulacan, Malolos	Provincial well		
62	49775	September, 1907	Bulacan, Bocaue	Driven well, 127.7 meters deep		
63	54721	January, 1908	Bulacan, Marilao	Driven well		
64	56949	February, 1908	Bulacan, Polo	do		
65	56965	March, 1908	do	do		
66	57479	do	do	do		
67	60639	September, 1908	Bulacan, San Jose	do	Brownish	Alkaline.
68	60640	do	Bulacan, San Miguel	do	Slightly brownish	Do.
69	78825	June, 1910	Bulacan, Calumpit	No. 162; 125 meters deep; flows 65 liters per minute.	Normal	Do.
70	85759	January, 1911	Bulacan, Baliuag	No. 224; 165 meters deep; flows 95 liters per minute.		Slightly alkaline.
71	87524	April, 1911	do	No. 246; 118.8 meters deep; flows 720 liters per minute.	Clear, brackish	Alkaline.
72	89432	June, 1911	do	No. 279; 163.4 meters deep; flows 114 liters per minute.		
73	97049	February, 1912	do	No. 345	Normal	Do.
74	98529	March, 1912	do	No. 364	do	Do.
75	102056	June, 1912	Bulacan, Santa Maria	No. 389	Brownish yellow	Do.
76	105141	July, 1912	Bulacan, Angat	No. 400		Do.
77	105809	do	Bulacan, Bulacan		Normal	Do.
78	109843	December, 1912	Bulacan, Norzagaray	No. 426	Brown with little red sediment	Do.
79	113638	May, 1913	Bulacan, Pulilan	No. 489; 233 meters deep; flows 150 liters per minute.	Normal	Do.

80	111547	January, 1913	Bulacan, Quingua	No. 472; 216.4 meters deep; flows 150 liters per minute.	do	Do.
81	115332	July, 1913	Bulacan, San Ildefonso	No. 513; 147.8 meters deep; flows 75 liters per minute.	do	
82	117442	September, 1913	Bulacan, San Rafael	No. 531; 174.3 meters deep; flows 95 liters per minute.	do	Neutral.
83	71804	September, 1909	Camarines, Nueva Caceres	No. 118; 107 meters deep; flows 190 liters per minute.	do	Do.
84	74040	November, 1909	do	No. 129; 57.6 meters deep; flows 151 liters per minute.	Brownish yellow	Acid.
85	97406	February, 1912	Camarines, Dasmariñas		Normal	Alkaline.
86	97798	do	Camarines, Daet	No. 3	Brownish yellow with little suspended brown sediment.	Do.
87	107343	do	Camarines, San Jose	No. 443	Normal	Neutral.
88	79649	July, 1910	Capiz, Capiz	No. 146; 306.3 meters deep; sample taken after pumping 48 hours at 75 liters per minute.		Slightly alkaline.
89	87656	April, 1911	do		Brownish	Alkaline.
90	13198	October, 1904	Cavite, naval station	158.5 meters deep		Do.
91	74811	December, 1909	Cavite, Cavite	No. 131; 160 meters deep; pumps 190 liters per minute.	Brownish	Neutral.
92	75304	do	Cavite, Rosario	No. 135; 27.4 meters deep; flows 40 liters per minute.	Normal	Do.
93	77152	February, 1910	Cavite, Ligtong, Noveleta	No. 141; 102.7 meters deep; flows 227 liters per minute.		
94	77565	March, 1910	Cavite, Naic	No. 147; 57 meters deep; pumps 56 liters per minute with hand pump.	Normal	Slightly alkaline.
95	77981	April, 1910	Cavite, Rosario	No. 135; 115.5 meters deep; flows 20 liters per minute.	do	Alkaline.
96	78903	June, 1910	Cavite, Caridad	No. 165; 136 meters deep; pumps 227 liters per minute.	do	Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—**Continued.**

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
97	80288	July, 1910	Cavite, Imus	No. 180; 71 meters deep; pumps 150 liters per minute.	Normal	Alkaline.
98	80469	August, 1910	do		Brown and turbid	Do.
99	80790	do	Cavite, San Roque	No. 182; 184 meters deep; flows 115 liters per minute.	Normal	Do.
100	81215	do	Cavite, Imus		do	Do.
101	82371	September, 1910	do		do	Do.
102	83352	October, 1910	do	No. 215; 76.2 meters deep; flows 26 liters per minute.	Turbid	Do.
103	83799	do	Cavite (Cavite No. 4)	No. 201; 183 meters deep; flows 183 liters per minute.		Do.
104	83950	November, 1910	Cavite, Imus		Normal	Do.
105	85530	January, 1911	Cavite, Bukangdala, Imus		Somewhat turbid	Do.
106	88873	June, 1911	Cavite, Santa Cruz de Malabon	No. 274; 59 meters deep; pumps 68 liters per minute.	Brown	Slightly alkaline.
107	88878	do	do	No. 289; 76.5 meters deep; pumps 75 liters per minute.	Brownish	Alkaline.
108	89998	July, 1911	Cavite, Amaya, Santa Cruz	No. 313; 924 meters deep; pumps 114 liters per minute.		
109	107605	October, 1912	Cavite, Santa Cruz de Malabon	No. 433	Normal with slight sediment	Do.
110	109674	December, 1912	do	No. 457	Normal	Do.
111	110193	do	do	No. 474	do	Do.
112	114008	May, 1913	Cavite, San Francisco de Malabon.	No. 503; 158.4 meters deep; flows 22 liters per minute.	do	Do.
113	112413	March, 1913	do	No. 479; 178.3 meters deep; pumps 56 liters per minute.	do	Do.
114	114934	June, 1913	do	No. 517; 51.8 meters deep; flows 75 liters per minute.	do	Do.

115	115333	July, 1913	do	No. 527; 112.7 meters deep; flows 56 liters per minute.		
116	116860	September, 1913	do	No. 532; 166 meters deep; pumps 170 liters per minute, water at 4.5 meters.	Brown	Neutral.
117	117443	do	do	No. 552; 112.7 meters deep; pumps 302 liters per minute.	do	Alkaline.
118	117646	October, 1913	Cavite, Rosario	No. 562; 115.8 meters deep; cased 94.4 meters; flows 22 liters; pumps 378 liters per minute.	Normal	Slightly alkaline.
119	117889	December, 1913	do	No. 585; 102.1 meters deep; cased 93.2 meters; flows 75 liters; pumps 378 liters per minute.	do	Neutral.
120	20914	August, 1905	Cebu, Cebu	Sample taken from stratum at 29 meters' depth.		Alkaline.
121	28301	March, 1906	do	Sample taken from adjacent well.	Very slightly turbid; considerable sediment and odor of hydrogen sulphide.	
122	29455	April, 1906	Cebu, Cebu, Cauit Island	Sample taken from stratum at 90 meters' depth.	Clear	
123	71504a	September, 1909	Cebu, Cebu	Municipal well	Normal	Slightly alkaline.
124	71504b	do	do	Customhouse well	do	Do.
125	73196	October, 1909	do	Municipal well	do	Alkaline.
126	73197	do	do	Customhouse well	do	Do.
127	75585	January, 1910	Cebu, on Cauit Island	Quarantine station	Brownish	Do.
128	117478	October, 1913	Cebu, Cebu	Well at Carbon public market		
129	112700	March, 1913	do		Normal	Do.
130	117474	October, 1913	do	Calle Juan Luna	do	Neutral.
131	117476	September, 1913	do	Near railway station	do	Do.
132	96990	February, 1912	Cebu, Mabolo estate	No. 327		Alkaline.
133	99397	April, 1912	Cebu, Argao	No. 736	Turbid with clayish sediment	Do.
134	97268	do	Cebu, Mabolo	No. 327	Normal	Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
135	114822	June, 1913	Cebu, Dalaguete	No. 473; 266.7 meters deep; pumps 227 liters per minute.	Normal	Alkaline.
136	58254	April, 1908	Corregidor Island	106.7 meters deep; flows 265 liters per minute.		Do.
137	88400	June, 1911	Corregidor, Fort Wint	No. 1	Slightly brownish	Do.
138	113543	May, 1913	Ilocos Sur, Candon	No. 482; 136.5 meters deep; pumps 52 liters per minute.	Slightly turbid	Do.
139	110499	December, 1912	do	No. 439	Normal; little brown sediment	Do.
140	16301	March, 1905	Iloilo, Iloilo	70 meters deep		
141	59352	July, 1908	Iloilo, Jaro			Do.
142	117452	October, 1913	do	No. 97; 176.7 meters deep; flows 26 liters per minute.	Brown	Neutral.
143	70374	August, 1909	do		Brownish yellow	Do.
144	72910	October, 1909	Iloilo, Santa Barbara	No. 122; 117.3 meters deep; flows 57 liters per minute.	Dark yellow	
145	74899	December, 1909	Iloilo, Jaro	No. 97; 178.3 meters deep; pumps 75 liters per minute.	Brownish yellow	Do.
146	75306	do	Iloilo, Santa Barbara	150.2 meters deep; flows 132 liters per minute.	Light brown	Very alkaline.
147	85947	January, 1911	Iloilo, Pototan	(a)	Slightly turbid	Slightly alkaline.
148	94862	January, 1912	Iloilo, Janiuay	No. 308	Deep brown color	Alkaline.
149	107186	September, 1912	Iloilo, Iloilo	No. 428	Salty, brown, little brown sediment	Slightly alkaline.
150	108062	October, 1912	do	No. 452	Brown-yellow; red-brown gelatinous sediment.	Alkaline.
151	109063	November, 1912	do	No. 461	Normal; red sediment	Do.
152	110053	December, 1912	do	No. 471	Brown; red sediment	Do.

153	117452	October, 1913	do	Customhouse well No. 3; 60.9 meters deep; flows 6 liters per minute. [c]		
154	117452	do	Iloilo, Santa Barbara	No. 122; 167.6 meters deep; flows 56 liters per minute.	Brown	Neutral.
155	111546	February, 1913	Iloilo, Molo	No. 480; 60.9 meters deep; flows 56 liters per minute.	Brown with sediment	Do.
156	113261	May, 1913	do	No. 500; 99 meters deep; flows 75 liters per minute.	Brown	Do.
157	115624	July, 1913	do	No. 530; 108.6 meters deep; flows 11 liters per minute.	Brown, turbid	
158	115940	August, 1913	do	At Plaza Libertad		
159	115941	do	do	At Concepcion Street	Turbid	
160	115942	do	do	At public market, Ignart Street		
161	115943	do	Iloilo, Mandurriao		Brown	Do.
162	115944	do	Iloilo, Iloilo	At provincial jail	Yellow-brown	
163	115945	do	do	At Mabini Street	Brown	
164	115947	do	do	Ortiz Street		
165	116157	do	do	At ice plant		
166	117271	do	do	No. 541; 91.4 meters deep; pumps 56 liters per minute.	Dark brown	Alkaline.
167	117739	do	do	No. 568; 78.9 meters deep; flows 11 liters per minute.	Reddish sediment	Slightly alkaline.
168	115946	do	Iloilo, Molo		Brown	Neutral.
169	58575	May, 1908	Laguna, Santa Cruz	No. 2	Turbid; brownish yellow	Alkaline.
170	67315	March, 1909	Laguna, Los Baños	70 meters deep	Brownish yellow	Do.
171	58171	April, 1908	Laguna, Santa Cruz			
172	58240	do	do			
173	58483	May, 1908	do	No. 1	Normal	Do.
174	92745	October, 1911	Laguna, San Pedro, Tunasan	No. 326; 108.2 meters deep; flows 40 liters per minute.	do	Do.
175	93552	November, 1911	Laguna, Biñan	No. 330; 93 meters deep; flows 60 and pumps 200 liters per minute.		Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
176	93927	November, 1911	Laguna, Biñan	No. 336; 74.7 meters deep; flows 120 liters per minute.		Alkaline.
177	94767	January, 1912	Laguna, Santa Rosa	No. 341	Normal	Slightly alkaline.
178	94992	do	Laguna, Cabuyao	No. 343	do	Alkaline.
179	94993	do	do	No. 347	do	Slightly alkaline.
180	97537	February, 1912	Laguna, Calamba	No. 356	do	Alkaline.
181	105449	July, 1912	Laguna, Pagsanjan		do	Neutral.
182	107603	October, 1912	Laguna, Santa Cruz	No. 440	Yellowish	Alkaline.
183	110480	December, 1912	do	No. 459	Normal	Do.
184	115625	June, 1913	Laguna, Lumbang	No. 526; 91.4 meters deep; flows 132 liters per minute.		
185	116335	July, 1913	do	No. 540; 128 meters deep; flows 227 liters per minute.	Yellowish brown	Neutral.
186	116824	August, 1913	do	No. 548; 95 meters deep; flows 151 liters per minute.	Normal	
187	114448	May, 1913	Laguna, Pila	No. 508; 154.8 meters deep; flows 321 liters per minute.	do	Alkaline.
188	111668	February, 1913	Laguna, Santa Cruz	No. 27; 175.2 meters deep; flows 757 liters per minute. [d]	Brown with red sediment	Do.
189	112984	April, 1913	do	No. 493; 169 meters deep; flows 927 liters per minute.	Brown with brown sediment	Do.
190	117609	October, 1913	Laguna, Siniloan	No. 553; 121.9 meters deep; flows 151 liters per minute.	Brown	Neutral.
191	117772	November, 1913	do	No. 566; 126 meters deep; flows 151 liters per minute.	Normal	Do.
192	68197	April, 1909	Leyte, Carigara	No. 78; 51.8 meters deep	Somewhat greenish in color; turbid	Alkaline.
193	68605	May, 1909	do	Sawang	Reddish sediment	Do.
194	68930	June, 1909	do	No. 93; 52 meters deep	Turbid	Do.

195	68956	do	do	No. 87; 69.2 meters deep	do	Do.
196	52172	November, 1907	Manila, Manila R. R. station yard.	Well under construction		
197	54050	December, 1907	do			
198	61233	October, 1908	Manila	(e)		
199	62824	December, 1908	do	(e)		
200	13985	November, 1904	Manila, Engineer Island			
201	15660	February, 1905	do			
202	15434	do	Manila, Singalong Farm			Do.
203	26700	December, 1905	Manila, Santa Ana	Driven well		
204	81219	September, 1910	Manila	Sample 3 e		
205	81219	do	do	Sample 4 e		
206	86704	February, 1911	do	Sample 3 e		
207	86910	March, 1911	do	(e)		
208	86910	do	do	Sample 4 e		
209	87142	April, 1911	Manila, Insular ice plant			Slightly alkaline.
210	90678	August, 1911	Manila	Sample 3 e		
211	91638	do	do	(e)		
212	92681	September, 1911	do	(e)		
213	93509	October, 1911	do	(e)		
214	97955	March, 1912	do	Sample 3 e	Brownish	Neutral.
215	99409	April, 1912	do	No. 3	Normal	Alkaline.
216	99409	do	do	No. 4	do	Do.
217	101821	May, 1912	Manila, No. 12 Calle Misericordia.		Turbid with clayey sediment	Do.
218	102237	do	Manila			
219	104361	June, 1912	Manila, Sanitary Steam Laundry.		Normal	Do.
220		October, 1912	Manila	No. 2, Bureau of Science	do	
221		November, 1912	do	do	do	
222		do	do	do	do	
223	15977	March, 1905	Masbate, Masbate		Yellowish	
224	44865	June, 1907	Mindoro, Bulalacao	Mansalay Spring		

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
225	77822	April, 1910	Mindoro, Mindoro Development Company.	Plantation	Normal	Neutral.
226	110865	December, 1912	Misamis, Cagayan	No. 410	Brownish yellow	Alkaline.
227	114604	May, 1913	do	No. 484; 167.6 meters deep: pumps 227 liters per minute.	Normal	Do.
228	79220	July, 1910	Nueva Ecija, Gapan	No. 179; 25 meters deep f	Slight brownish color	Do.
229	82585	September, 1910	do	No. 214; 24 meters deep; pumps 130 liters per minute.	Normal	Slightly alkaline.
230	94613	January, 1912	Nueva Ecija, Cabanatuan	No. 17	do	Do.
231	111866	February, 1913	Occidental Negros, San Carlos	No. 462; 138.6 meters deep; flows 56 liters per minute.	do	Alkaline.
232	117541	October, 1913	Palawan, Iwahig		do	Neutral.
233	117565	September, 1913	do	No. 525; 140.2 meters deep; pumps 94 liters per minute.	Brown with slight sediment	Alkaline.
234	36590	October, 1906	Pampanga, Lubao		Yellowish, earthy odor; some sediment.	Do.
235	38802	December, 1906	do			
236	38458	do	Pampanga, San Fernando			
237	38591	do	Pampanga, Mexico			
238	38585	do	Pampanga, Guagua			
239	38375	do	do			
240	38255	do	Pampanga, San Fernando			
241	38590	do	Pampanga, Bacolor			
242	39318	January, 1907	Pampanga, Santo Tomas			
243	43673	May, 1907	Pampanga, San Esteban	Well at the "Hacienda"		
244	45540	June, 1907	Pampanga, Sexmoan			
245	45539	do	Pampanga, San Fernando			
246	45538	do	Pampanga, Bacolor			

247	45537	do	Pampanga, Macabebe			
248	48313	August, 1907	Pampanga, Minalin	Driven well; flows 225 liters per minute.		
249	48311	do	Pampanga, Santo Tomas	Driven well		
250	48270	do	Pampanga, Bacolor	do		
251	48269	do	Pampanga, Lubao	do		
252	48263	do	Pampanga, Macabebe	Flows 225 liters per minute		
253	48268	do	Pampanga, Guagua			
254	48214	do	Pampanga, Mexico	Flows 35 liters per minute		
255	48210	do	Pampanga, San Fernando	Provincial well. Flows 35 liters per minute.		
256	48209	do	do	Municipal well		Do.
257	59195	June, 1908	do		Faint turbidity	
258	59706	July, 1908	Pampanga, Guagua		Brackish taste; brownish color	Do.
259	59955	August, 1908	Pampanga, San Jose, San Fernando.		Normal	
260	60083	do	Pampanga			Do.
261	60634	September, 1908	Pampanga, Minalin		Normal	Do.
262	61056	October, 1908	Pampanga, Sexmoan		do	Do.
263	61055	do	Pampanga, Santa Ana, Arayat		Slightly turbid	Do.
264	61343	do	Pampanga, Betis, Guagua		Brownish	
265	61945	November, 1908	Pampanga, Tinajero, Bacolor		Brownish yellow	Do.
266	62809	December, 1908	Pampanga, San Vicente, Bacolor.		Good	Do.
267	62810	do	Pampanga, Cabitacan, Bacolor		Brownish	Do.
268	62811	do	Pampanga, Cabalantian, Bacolor.		Good	Do.
269	64528	February, 1909	Pampanga, San Matias, Santa Rita.			
270	67352	March, 1909	Pampanga, San Vicente, Santa Rita.		Good	Do.
271	67351	April, 1909	Pampanga, Santa Monica, Santa Rita.		do	Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
272	67353	April, 1909	Pampanga, San Isidro, Santa Rita.		Good	Alkaline.
273	68469	May, 1909	Pampanga, San Juan, Santa Rita.		do	Do.
274	68470	do	Pampanga, San Vicente, Santa Rita.		do	Do.
275	68471	do	Pampanga, Santa Monica, Santa Rita		do	Do.
276	69116	June, 1909	Pampanga, Santa Rita	"S. Vicente" well	do	Do.
277	69117	do	Pampanga, San Juan, Santa Rita.		do	Do.
278	70464	August, 1909	Pampanga, San Luis	Sample "A"		Slightly alkaline.
279	70464	do	do	Sample "B"	Brown	Alkaline.
280	70908	September, 1909	Pampanga, San Fernando	Well in market	Brownish	Slightly alkaline.
281	72249	October, 1909	do	do	Slightly brown	Do,
282	72811	do	Pampanga, Santa Cruz, San Luis.	do	Normal	Do.
283	72811	do	Pampanga, San Luis		do	Do.
284	72964	do	Pampanga, San Juan, Santa Rita.		Good	Very alkaline.
285	75096	December, 1909	Pampanga, San Fernando		Brownish	Neutral.
286	106871	September, 1912	Pampanga, Candaba	No. 434		Alkaline.
287	108533	November, 1912	do	No. 450	Brownish, with little whitish sediment.	Do.
288	111327	January, 1913	Pampanga, Arayat	No. 470; 156.9 meters deep; pumps 302 liters per minute.	Normal with clayey sediment	Do.
289	113697	May, 1913	do	No. 492; 182.8 meters deep; pumps 189 liters per minute.	Normal	Do.

290	113343	April, 1913	Pampanga, Bacolor		do	Do.
291	116861	August, 1913	Pampanga, Mabalacat	No. 519; 217.9 meters deep; pumps 94 liters per minute.		
292	1076	February, 1903	Pangasinan, Bayambang	Artesian well; at depth of 157 meters.		Slightly acid.
293	60753	October, 1908	Pangasinan, Dagupan	do	Good	Alkaline.
294	64008	February, 1909	Pangasinan, Lingayen	No. 39	do	Do.
295	64559	March, 1909	do		Brownish	Do.
296	67973	April, 1909	Pangasinan, Dagupan	No. 75; 67 meters deep; flows 570 liters per minute.	Turbid; white flaky sediment	Neutral.
297	68617	May, 1909	Pangasinan, Calasiao	No. 80; 58 meters deep; flows 190 liters per minute.	Good	Very alkaline.
298	69625	July, 1909	Pangasinan, San Carlos	No. 90; 131.7 meters deep	Normal	
299	69857	do	Pangasinan, Bautista		Turbid and brownish	Alkaline.
300	80060	July, 1910	do	No. 181; 85 meters deep; flows 60 liters per minute.		Slightly alkaline.
301	85906	January, 1911	Pangasinan, Bayambang	No. 226; 117.3 meters deep; flows 5.7 liters, and pumps 95 liters.	Brownish; some sediment	Alkaline.
302	86306	February, 1911	Pangasinan (Bayambang No. 2).	No. 259; 37.4 meters deep; flows 1,900 liters per minute.	Sandy sediment	Do.
303	91192	August, 1911	Pangasinan, Malasiqui	No. 310; 91.4 meters deep; pumps 950 liters per minute.		
304	92450	October, 1911	Pangasinan, San Fabian	No. 325; 35 meters deep; flows 605 liters per minute.		Do.
305	93693	November, 1911	Pangasinan, Mangaldan	No. 328; 32 meters deep; flows 285 liters per minute.		Do.
306	94707	January, 1912	Pangasinan, Binmaley	No. 335	Odorless, turbid, of brown color	Slightly alkaline.
307	105444	July, 1912	Pangasinan, San Jacinto	No. 408	Normal	Alkaline.
308	106337	August, 1912	Pangasinan, Alcala	No. 415	do	Do.
309	106814	September, 1912	Pangasinan, Sual	No. 403	do	Do
310	108254	October, 1912	Pangasinan, Santo Tomas	No. 445	do	Do.
311	115144	June, 1913	Pangasinan, Binalonan	No. 521; 82.2 meters deep; pumps 454 liters per minute.		Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
312	117520	October, 1913	Pangasinan, Dagupan	No. 556; 67.9 meters deep; flows 227 liters per minute.	Normal	Alkaline.
313	114821	June, 1913	Pangasinan, Lingayen	No. 486; 268 meters deep; flows 757 liters per minute.	Brown-yellow	Do.
314	116862	September, 1913	do	No. 533; 166.4 meters deep; flows 170 liters per minute.		
315	117102	do	Pangasinan, Santo Tomas	No. 516; 178.9 meters deep; flows 60 liters per minute.		Neutral.
316	44380	May, 1907	Rizal, Fort William McKinley			
317	57372	March, 1908	do	No. 7; 265.8 meters deep		
318	59533	July, 1908	do	Wells from 230 to 320 meters deep; water supply from 7 wells.	Good	Markedly alkaline.
319	59580	do	Rizal, Government stock farm, Alabang.	No. 29	do	Do.
320	61809	November, 1908	Rizal, Fort William McKinley	No. 8; 244 meters deep	do	Alkaline.
321	65576	March, 1909	Rizal, Navotas		Brownish	Do.
322	67694	April 1909	Rizal, Pasay	No. 45; 178.5 meters deep; pumps 400 liters per minute.	Brackish taste	
323	67895	do	Rizal, Fort William McKinley	No. 9; 245 meters deep	Good	Do.
324	68170	May, 1909	Rizal, San Mateo	No. 77	Slightly brown	Do.
325	68454	do	Rizal, Pasay	228 meters deep; pumps 150 liters per minute.	Good	Do.
326	68960	June, 1909	Rizal, Malabon	176.8 meters deep; flows 35 liters per minute.	do	Do.
327	69291	July, 1909	Rizal, Parañaque	No. 99; 147.8 meters deep	Brownish; brackish taste	Do.
328	69815	August, 1909	do	183 meters deep	Turbid; salty taste	
329	70116	September, 1909	Rizal, Fort William McKinley	No. 10; 245.7 meters deep	Normal	

330	71619	October, 1909	Rizal, Caloocan	No. 105; 213.4 meters deep; flows 115 liters per minute.	do	Do.
331	72086	do	Rizal, Parañaque	No. 99; 243.8 meters deep; light flow.	do	
332	72529	do	Rizal, Polo Club, Pasay	No. 116; 220.7 meters deep	Good	
333	72622	do	Rizal, San Mateo	45.7 meters deep; pumps 75 liters per minute.	do	Slightly alkaline.
334	72622	do	Rizal, Montalban	18.3 meters deep; pumps 75 liters per minute.	do	Do.
335	72622	do	Rizal, Mariquina	21.3 meters deep; pumps 75 liters per minute.	Turbid; brownish color	Do.
336	74671	December, 1909	Rizal, Bayan-bayanan, Mariquina.	No. 1	Good	Acid.
337	74672	do	Rizal, Santo Niño, Mariquina	No. 2	Turbid and brownish	Neutral.
338	74673	do	do	No. 3	Brownish	Slightly alkaline.
339	74674	do	Rizal, San Roque, Mariquina	No. 6	Slightly brownish	Alkaline.
340	74675	do	Rizal, Calumpang, Mariquina	No. 7	Turbid	Do.
341	117455	September, 1913	Rizal, Antipolo	No. 557; 96 meters deep; pumps 132 liters per minute; water at 8.8 meters.	Normal	Acid.
342	117570	October, 1913	do	No. 565; 60.9 meters deep; cased 19.5 meters; pumps 133 liters per minute.	Turbid	Do.
343	80594	August, 1910	Rizal, Polo Club, Pasay	No. 115; 226.5 meters deep; pumps 190 liters per minute.	Greenish mossy sediment	Alkaline.
344	80095	do	Rizal, Pasig	No. 133; 268.2 meters deep	Greenish color; contains sediment	Do.
345	86832	March, 1911	Rizal, San Pedro Macati	No. 258; flows 11 and pumps 75 liters per minute.		Do.
346	86881	do	Rizal, Camp Gordon	No. 1, on Las Piñas-San Pedro Tunasan Road; 45 meters deep; pumps 150 liters per minute.		Do.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
347	86881	March, 1911	Rizal, Camp Hyson	No. 2, on Las Piñas-San Pedro Tunasan Road; 146 meters deep; pumps 75 liters per minute.		Alkaline.
348	87525	May, 1911	Rizal, Alabang	No. 257; 302 meters deep; pumps 375 liters per minute.	Brownish	Do.
349	88593	June, 1911	Rizal, Taytay	No. 272; 155.4 meters deep; pumps 225 liters per minute.	Turbid; clayey sediment	Do.
350	88594	do	Rizal, Alabang	No. 283; 173.7 meters deep; pumps 680 liters per minute.	Good	Do.
351	89163	July, 1911	Rizal, Pasay		Salty taste	Do.
352	94089	November, 1911	Rizal, Alabang		Normal	Slightly alkaline.
353	93776	December, 1911	Rizal, Antipolo	No. 323; 98.3 meters deep; pumps 190 liters per minute.		Alkaline.
354	94640	January, 1912	Rizal, Taytay	No. 340	Normal	Slightly alkaline.
355	96857	February, 1912	Rizal, Antipolo	No. 302	do	Neutral.
356	97143	do	Rizal, Antipolo magnetic station.		do	Do.
357	97863	do	Rizal, Tanay	No. 352	do	Alkaline.
358	97864	do	do	No. 355	do	Do.
359	97869	do	do	No. 362	Slightly turbid; little clayish sediment	Do.
360	98157	March, 1912	Rizal, Taytay	No. 344	Slightly milky	Do.
361	98991	April, 1912	Rizal, Pateros	No. 380	Turbid; salty; brown sediment	Do.
362	99331	do	Rizal, Las Piñas	No. 386	Normal	Do.
363	99488	do	Rizal, Antipolo		Turbid	Acid.
364	101739	May, 1912	Rizal, Tagig	No. 388	Normal	Alkaline.
365	101922	do	Rizal, Las Piñas	No. 392	do	Do.
366	104044	June, 1912	Rizal, Tagig	No. 394	do	Do.

367	104599	do	Rizal, Parañaque	No. 417	do	Do.
368	104529	July, 1912	do	No. 404	do	Do.
369	105142	do	do	No. 421	do	Do.
370	105271	do	Rizal, Montalban	No. 423	Somewhat turbid; red earthy sediment.	Do.
371	105638	do	Rizal, Parañaque	No. 424	Normal	Do.
372	106255	August, 1912	Rizal, Pasay	No. 429	do	Do.
373	107040	September, 1912	Rizal, Pasay, San Roque	No. 438	do	Do.
374	89828	July, 1911	Rizal, Pasay	No. 45; 228.5 meters deep; flows 150 liters per minute.	Salty taste	Do.
375	117683	October, 1913	Rizal, Antipolo	No. 570; 62.4 meters deep; cased 11.8 meters; pumps 150 liters per minute.	Normal	Acid.
376	117992	January, 1913	do	No. 557; 96 meters deep; pumps 132 liters per minute.	do	Alkaline.
377	112549	March, 1913	Rizal, Binangonan	No. 447; 213 meters deep; pumps 378 liters per minute.	Slight red sediment	Do.
378	112673	do	do		Normal	Do.
379	113818	April, 1913	do	No. 504; 93.8 meters deep; pumps 190 liters per minute; water at 6 meters.	Turbid	Do.
380	115973	August, 1913	Rizal, Jalajala	No. 520; 111.8 meters deep; pumps 75 liters per minute.		
381	117571	do	do	do	Brown and clear	Neutral.
382	116975	September, 1913	Rizal, Pililla, Kisao	No. 539; 56.9 meters deep; flows 20 liters per minute.		Alkaline.
383	114443	June, 1913	Rizal, Malabon	No. 512; 183.4 meters deep; flows 11 liters per minute.	Normal	Do.
384	115193	July, 1913	do	No. 524; 142.6 meters deep; pumps 150 liters per minute.		Do.
385	116336	August, 1913	do	No. 534; 161.5 meters deep; pumps 75 liters per minute.	Normal	Neutral.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
386	117673	October, 1913	Rizal, Malabon	No. 569; 117.3 meters deep; cased 103.5 meters; pumps 23 liters per minute.	Normal	Alkaline.
387	112498	March, 1913	Rizal, Montalban	No. 406; pumps 53 liters per minute.	do	Do.
388	113542	April, 1913	do	No. 498; 167.6 meters deep; pumps 75 liters per minute.	do	Do.
389	112499	March, 1913	do	No. 423; pumps 75 liters per minute.	Slight red sediment	Do.
390	112141	February, 1913	Rizal, Morong	No. 448; 271.2 meters deep; pumps 113 liters per minute.	Brown, with slight sediment	Do.
391	112476	March, 1913	San Pedro		Turbid	Do.
392	112897	April, 1913	do	No. 448; 271.2 meters deep; pumps 113 liters per minute.	Normal	Do.
393	112898	do	do	No. 502; 91.4 meters deep; pumps 75 liters per minute.	do	Do.
394	113093	do	do	Well at San Juan	do	Do.
395	117558	October, 1913	do	No. 448; 271.2 meters deep; cased 88.3 meters; pumps 113 liters per minute.	do	Do.
396	117554	do	do	No. 502; 91.4 meters deep; pumps 75 liters per minute.	do	Do.
397	117555	do	do	No. 546; 29.8 meters deep; pumps 132 liters per minute.	do	Neutral.
398	117895	December, 1913	Rizal, Navotas, Tanza	No. 579; 212.7 meters deep; flows 10 and pumps 95 liters per minute at 7 meters from surface.	do	Alkaline.

399	114276	May, 1913	Rizal, Tanay	No. 506: 91.4 meters deep; pumps 378 liters per minute.		
400	112114	February, 1913	Rizal, San Mateo	No. 466; 264.7 meters deep; pumps 140 liters per minute.	Light brown, with gray sediment	
401	70624	September, 1909	Romblon, Carabao Island, No. IV			Neutral.
402	70355	do	Samar, Catbalogan	Artesian well	Good	Do.
403	94869	January, 1912	do	No. 311	Brownish, turbid, and odorless	Slightly alkaline.
404	105977	August, 1912	Samar, Wright	No. 393	Brownish	Alkaline.
405	105993	do	Samar (?)			Do.
406	117681	October, 1913	Samar, Villareal	No. 441; 320 meters deep; cased 216.4 meters; pumps 37 liters per minute.	Brown	Do.
407	115467	July, 1913	Sorsogon, Bacon	No. 491; 174.3 meters deep; pumps 113 liters per minute.		
408	117451	September, 1913	Sorsogon, Casiguran	No. 537; 158.4 meters deep; pumps 75 liters per minute.	Yellow brown	Neutral.
409	117988	December, 1913	do	No. 560; 163 meters deep; cased 123.4 meters; pumps 56 liters per minute at 4.8 meters.		Alkaline.
410	107944	October, 1912	Sorsogon, Sorsogon	No. 437	Normal with slight sediment	Do.
411	110866	December, 1912	do	No. 456	Turbid with reddish sediment	Do.
412	80297	August, 1910	Tarlac, Tarlac	Municipal well; 64 meters deep; pumps 75 liters per minute.	Turbid; brownish; greenish sediment	Do.
413	107344	September, 1912	Tarlac, Camiling	No. 419	Brownish; red earthy sediment	Neutral.
414	108992	November, 1912	do	do	Normal; little red sediment	Alkaline.
415	110789	December, 1912	do	No. 451	Somewhat turbid; reddish sediment	Do.
416	117689	October, 1913	Tarlac, Gerona	No. 549; 193.8 meters deep; cased 159 meters; pumps 132 liters per minute.	Brown	Do.
417	116713	August, 1913	Tarlac, Tarlac	No. 509; 234.6 meters deep; pumps 264 liters per minute.	do	Neutral.
418	113292	May, 1913	Tarlac, Camiling	No. 478; 181 meters deep; pumps 75 liters per minute.		

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	No. of well and description.	Physical properties.	Reaction.
419	80287	August, 1910	Tayabas, Lucena	No. 178; 105.3 meters deep; flows 45 liters per minute.	Brownish yellow; earthy sediment	Alkaline.
420	80450	do	Tayabas, Gasan, Marinduque	Municipal well; 48.8 meters deep; flows 4 and pumps 20 liters per minute.		Do.
421	81495	September, 1910	Tayabas, Lucena	No. 178; 164 meters deep; flows 115 liters per minute.	Brownish	Slightly alkaline.
422	83798	November, 1910	do	do	Brownish	Alkaline.
423	84983	January, 1911	Tayabas, Lucena	No. 212; 205.4 meters deep; flows 75 liters per minute.		Do.
424	85646	do	Tayabas, Boac, Marinduque	No. 1; 54.8 meters deep; pumps 60 liters per minute.		
425	87523	May, 1911	do	No. 2	Brownish	Do.
426	87526	do	do	No. 3; 47 meters deep; flows 10 and pumps 35 liters per minute.	Brownish yellow	Do.
427	96819	February, 1912	Tayabas, Pagbilao	No. 316	Normal	Do.
428	105742	August, 1912	Tayabas, Atimonan	No. 359	do	Do.
429	113237	April, 1913	Tayabas, Lucena	Hospital de Pobres	do	Do.
430	99418	April, 1912	Zambales, San Narciso	No. 1	Yellow with brownish sediment	
431	99418	do	do	No. 2	Normal	Do.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

[E = excessive; L = little; N = nil; P = present; T = trace; U = undetermined.]

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
1	86551	1,336.8	1,291.2	45.6	11.880	0.314	N	T	620.0			Blackening and evolution of hydrochloric acid.
2	117705	1,826.0			0.171	0.021	N	T	964.03			
3	112669	450.4	441.0	9.4	5.301	0.046	N	N	32.01			
4	118001	992.8			1.165	0.193	T	0.0002	217.7			Contains much organic matter.
5	115366	605.2			3.357	0.495	L	N	106.9			
6	117935	288.0			0.024	0.067	N	N	12.31			
7	117935	300.8			0.256	.087	N	N	12.31			
8	117935	277.2			0.014	0.101	N	N	2.46			
9	117935	265.6			0.019	0.101	N	N	4.43			
10	117935	287.2			0.043	0.113	N	N	13.3			
11	117935	274.8			0.024	0.056	N	N	3.45			
12	117935	298.4			0.125	0.053	N	N	12.31			
13	117462	382.8			0.007	0.007	L	N	4.41			
14	70173	5,072.4	5,039.6	32.8	0.054	0.13[3]	T	0.053	2598.03	N	292.0	
15	78712	395.2	389.6	5.6	0.031	L	N	T	7.38	N	227.0	
16	79221	378.4	349.6	28.8	0.087	0.036	N	N	8.45	N	186.8	
17	79230	1,075.0	1,007.0	68.0	0.013	0.101	T	N	346.80			
18	62394	364.8	314.0	50.8	0.006	0.017	0.065	T		N	171.71	
19	68518	702.8	671.2	31.6	0.135	0.097	1.281	0.736	5.4	N	199.25	Darkening.
20	117608	366.8			0.065	0.036	2.048	T	8.5			
21	117610	417.2			0.007	0.242	0.724	0.08	7.0			Contaminated with organic matter; contained *B. coli*.
22	117897	377.2			0.028	0.056	U	U	6.89			
23	117444	379.6			0.017	0.007	N	N	5.63			

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
24	113010	362.6	349.4	13.2	0.012	0.033	1.112	N	7.8	....	....	
25	117898	363.2	....	....	0.021	....	P	N	4.18	....	....	
26	112113	362.4	343.2	19.2	0.005	0.031	1.33	T	7.42	....	....	
27	117463	488.8	....	....	0.026	0.007	U	N	25.0	....	....	
28	93292	640.2	639.4	0.8	0.348	0.010	N	N	58.44	....	....	
29	95430	646.7	571.8	74.9	0.159	0.099	0.003	0.026	216.9	17.0	129.2	Brownish white.
30	98447	1,276.2	1,274.4	1.8	0.864	0.135	T	T	455.39	....	....	Slight browning.
31	105125	295.4	273.4	22.0	0.111	0.120	U	0.110	7.84	....	....	
32	108462	325.2	316.0	9.2	0.019	0.023	T	N	12.3	....	....	
33	109934	276.0	269.0	7.0	0.034	0.050	T	N	9.4	....	....	
34	115331	266.8	....	....	0.007	0.029	N	N	6.93	....	....	
35	112111	124.4	....	L	0.005	0.014	N	N	2.47	....	....	
36	115133	786.0	....	....	0.833	0.326	N	N	394.45	....	....	
37	117402	786.8	....	....	1.367	0.077	N	N	400.49	....	....	
38	74676	456.8	420.0	36.8	L	0.043	3.043	T	74.63	....	....	
39	79477	411.6	....	....	3.562	0.096	....	1.030	11.27	....	....	
40	79478	523.6	....	....	1.859	0.036	N	N	30.39	....	....	
41	117767	1,124.0	....	....	0.029	0.029	L	T	409.3	....	....	
42	79479	464.8	....	....	0.010	0.022	....	0.883	28.43	....	....	
43	80289	2,146.8	2,144.4	82.4	0.094	0.033	N	N	985.15	248.2	78.2	Evolution of hydrochloric acid.
44	81901	1,265.6	1,173.2	92.4	0.036	0.077	5.854	0.003	502.91	....	....	Evolution of hydrochloric acid and oxide of nitrogen.
45	83330	464.0	449.2	14.8	E	0.104	T	0.30	27.58	....	....	Blackening.
46	83331	565.2	514.4	50.8	0.005	0.039	0.625	0.400	41.38	....	....	Slight browning.
47	83717	2,547.8	2,331.3	216.5	0.009	0.005	T	N	1,099.5	....	....	Darkens slightly.
48	83743	1,458.2	1,401.2	57.0	0.011	0.014	0.833	N	591.1	....	....	Slight browning.

49	85093	2,244.2			0.084	0.024	N	T	992.23			
50	85750	323.6			0.021	0.034	0.469	T	6.21			Slight blackening.
51	87828	330.8		L	0.002	0.009	0.724	N	7.84			
52	88706	1,425.4	1,353.6	71.8	0.002	0.017	T	T	631.68			Slight browning and evolution of hydrochloric acid.
53	91226	1,603.6	1,552.2	51.4	0.021	0.014	1.125	T	666.66			
54	96694	702.3	576.8	125.5	0.775	0.059	0.004	0.8	139.2	109.5	151.3	White on ignition.
55	42392	1,016.6	934.1	82.5	0.304	0.015			458.4			
56	42794	970.6	884.6	86.0	0.024	0.009	T	0.23	423.3	119	37	Very slight blackening.
57	43533	700.2	657.8	42.4	0.269	0.024	N	N	232.68	42.9		
58	44052	1,391.8	1,330.8	61.0	0.056	0.001	T	0.012	648.6	140.6		
59	46442	397.9	379.6	18.3	0.044	0.029	N	N	103.4	12.70		Positive blackening.
60	47956	402.7	400.3	2.4	0.052	0.018	N	N	101.7			
61	47957	610.9	599.6	11.3	0.049	0.008	N	N	155.7			
62	49775	262.6	245.5	17.1	0.048	0.015	N	N	25.87	N	71.0	Slight blackening.
63	54721	220.4	207.8	12.6	0.007	0.021	T	T	12.1			Little blackening.
64	56949	231.2	203.2	28.0	0.017	0.057	T	N	19.6			Positive blackening.
65	56965	214.8	197.4	17.4	0.042	0.046	N	N	11.82			Slight blackening.
66	57479	216.8	194.4	22.4	0.036	0.005	N	N	11.8			Do.
67	60639	375.6	358.8	16.8	0.171	T	N	N	89.11			Slight darkening.
68	60640	400.0	386.4	13.6	0.104	0.009	T	0.048	118.81			Slight browning.
69	78825	343.4	341.0	2.4	0.183	0.052	N	N	49.43	N	31.3	
70	85759	1,011.2	998.0	13.2	0.280	0.019	N	T	506.73			
71	87524	1,095.4	1,089.2	6.2	0.391	0.057	N	N	598.04			
72	89432	1,049.2		T	0.041	0.043	N	0.244	564.35			Browning.
73	97049	1,114.3	1,081.8	32.5	0.365	0.031	0.004	N	607.2	47.9	25.5	
74	98529	896.4	891.0	5.4	0.246	0.067	N	N	474.51			
75	102056	280.0	S		0.164	0.087	P	T	17.64			Slight blackening.
76	105141	1,339.6	1,319.0	20.6	0.401	0.125	N	N	737.25			
77	105809	597.0			0.372	0.040	T	T	164.7			
78	109843	821.6	811.2	10.4	0.265	0.072	N	N	439.6			Blackening.
79	113638	846.8	816.8	30.0	0.323	0.024	N	N	16.0			
80	111547	871.2	859.2	12.0	0.343	0.082	T	T	423.6			

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as—				Chlorine.	Hardness.		Behavior of residue on ignition, and remarks.
					Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		Permanent.	Temporary.	
81	115332	769.6	----------	----------	0.292	0.022	N	N	386.5	----------	----------	
82	117442	2,233.2	----------	----------	0.449	0.053	N	N	760.29	----------	----------	
83	71804	394.6	386.6	8.0	0.079	0.082	1.967	0.025	18.53	8.26	221.0	Slight blackening.
84	74040	120.2	106.0	14.2	0.026	0.174	0.018	N	6.27	N	30.4	Positive blackening.
85	97406	491.6	482.8	8.8	1.207	0.724	N	N	152.94	----------	----------	Little blackening.
86	97798	1,527.2	1,434.0	93.2	0.761	0.217	P	0.01	590.19	----------	----------	Little blackening and evolution of hydrochloric acid.
87	107343	284.4	268.2	16.2	0.857	0.108	T	0.70	2.97	----------	----------	Slight coloration and smell of burnt earth.
88	79649	2,873.4	2,871.8	1.6	0.212	0.009	N	N	1502.45	758.4	T	
89	87656	1,722.8	1,694.4	28.4	0.051	0.041	T	N	719.61	----------	----------	Browning and evolution of hydrochloric acid.
90	13198	476.0	376.0	100.0	N	0.016	0.7	T	57.12	----------	----------	
91	74811	497.8	487.6	10.2	0.123	0.058	T	N	79.17	N	32.0	
92	75304	353.6	334.0	19.6	0.007	0.011	N	N	8.6	N	146.0	
93	77152	----------	----------	----------	----------	----------	----------	----------	2.48	----------	----------	
94	77565	354.8	342.0	12.8	0.021	0.019	N	T	9.38	N	133.5	
95	77981	425.6	410.0	15.6	0.118	0.017	N	T	14.183	N	101.25	
96	78903	512.4	510.0	2.4	0.398	0.169	N	T	31.58	N	43.05	
97	80288	380.8	----------	----------	0.036	0.009	T	T	9.65	11.46	144.44	
98	80469	313.4	303.0	10.4	0.007	0.057	T	T	11.76	----------	----------	
99	80790	514.6	----------	T	0.171	0.016	T	N	76.47	2.9	7.59	
100	81215	379.6	356.0	23.6	0.047	0.026	T	N	7.60	----------	----------	
101	82371	384.2	341.2	43.0	0.019	0.036	T	N	7.49	----------	----------	
102	83352	396.8	381.0	15.8	0.005	0.022	T	N	11.82	----------	----------	Brownish.
103	83799	500.8	499.4	1.4	0.130	0.008	T	N	80.0	----------	----------	No perceptible darkening.

104	83950	409.0	388.2	20.8	0.007	0.009	T	0.008	16.0			Brownish.
105	85530	387.4			0.017	0.012	T	N	6.99			
106	88873	396.2	382.4	13.8	0.002	0.002	T	T	9.90			Blackening.
107	88878	390.6	378.0	12.6	0.002	0.005	T		9.900			Do.
108	89998	347.6	339.2	8.4	0.007	0.002	T	0.003	5.94			Slight blackening.
109	107605	415.8	387.6	28.2	0.050	L	0.014	T	22.3			Browning.
110	109674	410.0	393.6	16.4	0.031	0.009	N	N	14.4			
111	110193	367.4	357.0	10.4	0.014	0.029	N	N	6.86			Blackening.
112	114008	408.8	387.6	21.2	0.111	0.012	N	T	19.0			
113	112413	383.8	363.2	20.6	0.024	0.024	N	N	15.8			
114	114934	362.0			0.007	0.012	T	0.012	6.93			
115	115333	388.8			0.055	0.021	N	N	9.9			
116	116860	397.6			0.077	0.019	N	N	13.72			
117	117443	408.0			0.055	0.024	N	N	10.29			
118	117646	442.0			0.073	0.012	N	T	12.0			
119	117889	417.2			0.139	0.043	N	N	12.56			
120	20914	1,499.0	1,473.5	25.5	0.074	0.166	T	T				
121	28301	1,629.0	52.0	1,577.0	0.060	0.220	N	N	507.60			
122	29455	2,583.8	2,515.8	68.0	0.070	0.180	N	N	1,110.80			
123	71504a	454.4	446.0	8.4	0.069	0.026	0.908	T	21.07			
124	71504b	604.4	602.8	1.6	0.058	0.458	0.851	0.005	34.34	N	106.0	
125	73196	468.4	464.0	4.4	0.041	0.019	0.661	0.001	16.831			
126	73197	664.0	652.0	12.0	0.072	0.048	0.679	T	42.37			
127	75585	5,652.0					T	T	2,796.8			
128	117478	540.0			0.031	0.031	U	N	18.13			
129	112700	868.8			0.029	0.043	0.697	N	183.1			Well used by customs office for ships at Cebu.
130	117474	397.6			0.014	0.007	P	N	9.56			
131	117476	391.2			0.010	0.007	T	N	6.86			
132	96990	376.0	326.5	49.5	0.014	0.039	0.02	0.0005	12.4	U	U	Total hardness, 154.4.
133	99397	521.2	520.8	0.4	0.118	0.082	T	T	116.66			Slight blackening.
134	97268	318.2	310.0	8.2	N	T	0.005	T	7.84			Slight browning.
135	114822	1,420.0			0.007	0.019	L	T	534.6			

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	Chlorine.	Hardness. Permanent.	Temporary.	Behavior of residue on ignition, and remarks.
136	58254	664.0	581.2	82.8	0.018	0.128	N	N	86.46	N	238.0	Blackening.
137	88400	4,151.8	3,209.4	942.4	0.031	0.029	L	T	1,822.00			Excessive blackening and evolution of much hydrochloric acid.
138	113543	2,483.2	2,437.6	45.6	0.007	0.122	1.883	0.020	1085.0			
139	110499	1,359.6	1,349.0	10.6	0.0145	0.116	T	1.20	235.3			Blackening.
140	16301	2,348.0	1,980.0	368.0	4.80	0.228	N	T	860.0			Blackening and slight odor.
141	59352	892.8	874.8	18.0						81.0	464.0	
142	117452	2,986.0			17.87	0.603	N	N	1243.6			
143	70374	2,891.6	2,878.0	13.6	13.524	0.656	N	N	1247.52	N	184.0	Little blackening.
144	72910	1,498.4	1,441.2	57.2	6.448	1.497	N	N				Blackening.
145	74899	2,898.8	2,872.0	26.8	20.39	0.410	N	N	1251.5	N	182.0	Slight blackening.
146	75306	1,202.4	1,192.0	10.4	8.259	0.229	N	N		N	60.2	
147	85947	631.6			0.041	0.077	3.718	0.007	75.73			Browning; little earthy sediment.
148	94862	8,197.5	7,950.2	247.3	over 9.0	1.79	(b)	(b)	4471.0	15.4	471.3	Brownish white on ignition.
149	107186	2,158.4	2,125.4	33.0	5.506	0.302	L	T	726.5			Blackening.
150	108062	2,244.8	2,214.8	30.0	6.605	0.326	N	N	792.1			Do.
151	109063	2,746.0	2,563.5	182.5	6.569	0.326	L	T	1049.0			Do.
152	110053	2,153.2	2,115.2	38.0	5.240	0.326	N	N	694.8			Do.
153	117452	2,216.8			4.842	0.217	L	0.01	867.15			
154	117452	1,113.6			7.534	0.386	N	N	237.74			Contains much organic matter.
155	111546	1,509.6	1,471.6	38.0	7.848	0.398	L	0.16	356.0			Do.
156	113261	2,134.8			6.158	0.229	N	N	792.0			
157	115624	3,289.2			22.6	0.157	L	T	1520.8			
158	115940	2,267.0			1.739	1.207	L	N	866.3			
159	115941	3,130.0			6.798	1.292	L	N	1044.5			
160	115942	2,165.0			4.395	0.543	L	N	797.03			

161	115943	1,452.0	....	....	3.755	0.350	L	N	275.25	....	....	
162	115944	2,368.0	....	....	1.690	2.427	L	N	792.1	....	....	
163	115945	2,158.0	....	....	5.119	0.326	L	N	704.9	....	....	
164	115947	2706.0	....	....	5.361	0.664	L	N	831.7	....	....	
165	116157	....	....	....	3.333	0.266	L	2.8	935.6	....	....	
166	117271	1140.0	....	....	8.633	0.388	N	N	235.78	....	....	Contains organic matter.
167	117739	3854.4	....	....	9.008	0.253	T	T	1791.6	....	....	
168	115946	1614.0	....	....	10.312	0.350	L	N	390.1	....	....	Do.
169	58575	452.4	378.0	74.4	14.490	0.270	N	N	19.59	N	161.6	Blackening and odor of burnt organic matter.
170	67315	794.4	756.0	38.4	32.690	1.188	N	N	24.46	N	231.2	Blackening and slight vegetable organic odor; well contains natural gas.
171	58171	218.8	202.0	16.8	0.004	0.003	T	N	5.5	....	71.0	Slight browning.
172	58240	217.6	187.2	30.4	0.273	0.002	T	N	5.55	....	....	
173	58483	220.4	193.0	27.4	0.410	0.099	T	T	5.55	N	80.00	Browning.
174	92745	399.0	389.6	9.4	0.046	0.012	T	T	6.93	....	....	
175	93552	392.5	314.4	78.1	0.05	0.010	0.004	0.001	15.0	N	282.6	
176	93927	381.9	291.3	90.6	0.477	0.067	N	0.01	12.40	N	362.0	
177	94767	394.0	324.7	69.3	0.017	T	N	0.05	16.18	45.8	269.9	
178	94992	755.1	706.0	49.1	0.029	0.005	T	0.001	12.81	17.4	254.2	
179	94993	350.2	300.0	50.2	0.009	T	N	0.001	16.47	N	256.6	
180	97537	367.8	....	....	0.048	0.017	T	T	8.33	....	....	
181	105449	824.2	766.2	58.0	0.017	0.050	T	T	190.20	....	....	Little blackening and evolution of hydrochloric acid.
182	107603	492.6	466.6	26.0	12.47	0.350	T	T	24.2	....	....	Slight blackening.
183	110480	454.0	434.0	20.0	9.877	0.193	T	N	19.6	....	....	Blackening.
184	115625	261.2	....	....	0.430	0.029	N	N	13.36	....	....	
185	116335	316.0	....	....	1.376	0.060	N	N	10.29	....	....	
186	116824	292.4	....	....	1.89	0.108	T	N	12.7	....	....	
187	114448	214.8	....	T	0.773	0.103	N	N	5.4	....	....	
188	111668	428.0	410.8	17.2	10.870	0.435	T	T	20.2	....	....	
189	112984	450.4	440.8	9.6	9.998	0.567	T	N	19.7	....	....	
190	117609	228.8	....	....	0.954	0.181	N	T	17.5	....	....	

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Nitrogen as— Albuminoid ammonia.	Nitrogen as— Nitrates.	Nitrogen as— Nitrites.	Chlorine.	Hardness. Permanent.	Hardness. Temporary.	Behavior of residue on ignition, and remarks.
191	117772	242.4			0.439	0.096	T	N	13.3			
192	68197	1274.4	1241.6	32.8	1.328	0.042	N	N	34.7	N	950.5	
193	68605	1304.2	1237.2	67.0	1.413	0.096	N	N	35.92			Darkening.
194	68930	1485.2	1396.8	88.4	1.570	0.024	T	N	43.36	N	1051.7	Turbidity due to precipitation of carbonates.
195	68956	1180.4	1081.2	99.2	0.116	0.014	T	0.920	38.76	N	826.6	Browning; turbidity due to precipitation of carbonates.
196	52172	8224.0	6724.0	1500.0	0.511	0.050	N	N	4266.6			Evolution of hydrochloric acid.
197	54050	1796.0	1695.4	100.6	0.166	0.031	N	N	873.5			Do.
198	61233				0.026	N	N	T	89.11			
199	62824	328.4	312.8	15.6	0.001	0.012	T	T	82.94			
200	13985	875.0	830.0	45.0	0.136	0.050	0.144	N	370.0			Very slight blackening and odor.
201	15660	829.0	801.0	28.0	0.128	0.062	0.232	T	344.0			
202	15434	896.0	828.0	68.0	0.114	0.110	0.186	T	194.0			
203	26700	1035.0		112.0	0.690	0.43			219.4	552.0		
204	81219				0.005	0.041	T	T				
205	81219				0.005	0.041	T	T				
206	86704				0.024	0.058	T	N				
207	86910	160.2	149.0	11.2	0.009	0.062		T	72.81			
208	86910	160.6	148.6	12.0	0.009	0.063		T	72.81			
209	27142	260.8	235.6	25.2	0.082	0.149	T	T	48.54			Positive blackening.
210	90678				0.087	0.046	N	N				
211	91638				0.014	0.038	T	T	91.4			
212	92681				0.007	0.014	P	T	82.18			
213	93509				0.007	0.017	T	T	65.54			
214	97955	338.8	324.4	14.4	0.048	0.024	T	T	89.2			Little blackening.

215	99409	294.8	286.6	8.2	0.029	0.077	T	T	75.49			Little blackening.
216	99409	342.2	334.8	7.4	0.019	0.060	T	0.004	90.19			Do.
217	101821	270.8			0.065	0.048	T	T	31.37			Do.
218	102237				0.0145	0.0265	T	0.006	87.25			
219	104361	253.0	242.6	10.4	0.067	0.048	T	N	35.29			Do.
220		527.0			0.120	0.022	T	T	12.90			
221		502.4			0.113	0.017	N	N	12.30			
222		510.0			0.113	0.034	T	N	12.30			
223	15977	1,950.8	1,826.2	124.6	0.024	0.120	T	T	436.3	64.30	33.80	
224	44865	476.4	368.2	108.2	0.004	0.014	T	T	38.1			
225	77822	146.4	137.6	8.8	0.055	0.067	0.093	T	12.85	16.6	90.0	Do.
226	110865	1,446.0	1379.2	66.8	2.741	0.169	L	N	550.0			Slight blackening.
227	114604	472.8			0.002	0.034			27.7			
228	79220	573.4	541.8	31.6	0.053	0.055	8.696	0.051	76.30	158.4	276.9	
229	82585	324.4	300.6	23.8	0.007	0.007	0.151	0.002	11.03	12.6	187.9	
230	94613	240.0	227.5	12.5	0.09	0.013	T	0.0005	28.92	N	161.5	
231	111866	313.2			0.005	0.026	T	0.052	7.9			
232	117541	28.4			0.270	0.026	N	N	T			
233	117565	412.0			0.082	0.041	N	N	11.5			
234	36590	311.40	273.2	38.2	1.80	0.34	T	0.20	T			Do.
235	38802	318.2	264.2	54.0	1.507	0.140			3.91			Positive blackening.
236	38458	436.0	408.0	28.0	0.674	0.036	T	N	31.74			
237	38591	429.0	398.2	30.8	0.185	0.042			34.01			
238	38585	1,200.0	1,136.4	63.6	2.98	0.21	0.02		248.5			Slight blackening.
239	38375	1,262.8	1,170.2	92.6	2.19	0.33		T	510.62			Slight blackening; fixed solids slightly reddish.
240	38255	448.6	398.4	50.2	0.24	0.07		T	34.0			Very slight blackening.
241	38590	451.6	423.6	28.0	0.286	0.067			14.34			Slight blackening.
242	39318	465.0	335.C	130.0	0.014	0.082	T	2.0	4.4			
243	43673	1,019.0	982.4	36.6	1.428	0.008	N	N	134.9			
244	45540	1,381.2	1,273.2	108.0	9.208	0.752	N	N				Blackening.
245	45539	478.6	432.0	46.6	0.270	0.103	N	0.015	30.3			Little darkening.
246	45538	469.8	412.8	57.0	0.383	0.059	N	N	17.25			Positive browning.

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as—				Chlorine.	Hardness.		Behavior of residue on ignition, and remarks.
					Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		Permanent.	Temporary.	
247	45537	366.6	316.0	50.6	0.005	0.065	N	N	58.9	----------	----------	Positive browning.
248	48312	234.2	232.8	1.4	0.269	0.040	N	0.007	9.24	----------	----------	
249	48311	243.8	243.0	0.8	0.370	0.018	N	N	7.8	----------	----------	
250	48270	446.8	441.6	5.2	0.270	0.050	N	0.024	13.9	----------	----------	
251	48269	314.8	304.0	10.8	1.849	0.095	N	N	3.45	----------	----------	
252	48263	359.0	356.4	2.6	0.487	0.063	N	N	58.20	----------	----------	
253	48268	1,207.0	1,187.2	19.8	2.518	0.059	N	N	305.3	----------	----------	Browning and organic odor.
254	48214	433.6	429.0	4.6	0.296	0.029	N	N	34.5	----------	----------	
255	48210	422.6	418.0	4.6	0.076	0.002	N	T	55.3	----------	----------	
256	48209	439.6	437.0	2.6	0.517	0.008	N	N	30.5	----------	----------	
257	59195	467.6	443.2	24.4	0.195	0.038	N	N	30.4	----------	----------	Slight darkening.
258	59706	1138.0	1075.2	62.8	1.811	0.227	T	N	267.30	----------	----------	Little blackening.
259	59955	491.2	460.8	30.4	0.700	0.101	N	N	20.39	----------	----------	
260	60083	1137.2	1080.0	57.2	3.019	0.181	N	0.056	263.36	----------	----------	Do.
261	60634	231.2	208.8	22.4	0.229	0.145	N	N	9.30	----------	----------	Slight browning.
262	61056	495.2	453.6	41.6	0.003	0.019	T	1.05	16.38	----------	----------	
263	61055	286.8	244.8	42.0	0.003	0.002	N	N	7.18	----------	----------	Little blackening.
264	61343	995.6	940.4	55.2	1.463	0.048	N	N	246.53	----------	----------	Blackening.
265	61945	574.8	524.8	50.0	3.972	0.2173	N	N	31.485	----------	----------	Positive blackening.
266	62809	425.2	372.8	52.4	0.3381	0.0845	0.0019	0.002	13.48	----------	----------	Slight darkening.
267	62810	652.8	613.6	39.2	1.425	0.1207	T	N	42.156	----------	----------	Little blackening.
268	62811	523.6	493.2	30.4	0.193	0.030	N	0.19	36.27	----------	----------	
269	64528	247.6	216.0	31.6	0.688	0.060	N	N	6.78	----------	----------	Blackening.
270	67352	257.2	241.8	15.4	0.314	0.087	T	0.24	8.37	----------	----------	
271	67351	263.6	262.8	0.8	0.616	0.082	N	N	8.14	----------	----------	
272	67353	249.0	239.2	9.8	0.628	0.116	N	0.038	7.60	----------	----------	

273	68469	315.6	298.4	17.2	0.555	0.018	N	N	8.36	....	....	Little blackening.
274	68470	260.0	248.8	11.2	0.483	0.048	N	N	7.96	....	....	Slight darkening.
275	68471	292.4	255.2	37.2	0.459	0.096	N	N	8.16	....	....	Darkening.
276	69116	258.8	251.2	7.6	0.543	0.024	N	N	8.72	....	....	
277	69117	314.8	301.2	13.6	0.664	0.072	N	N	8.12	....	....	Do.
278	70464	277.2	268.4	8.8	0.256	T	T	N	12.64	....	....	Little blackening.
279	70464	480.4	478.4	2.0	0.178	0.017	T	N	32.35	....	....	Browning.
280	70908	404.4	396.0	8.4	0.543	0.014	N	N	10.58	....	....	Slight blackening.
281	72249	397.2	390.0	7.2	0.565	0.024	N	N	10.48	....	....	
282	72811	....	....	....	0.287	0.036	N	N	11.65	....	....	
283	72811	....	....	....	0.386	0.116	N	N	32.23	....	....	
284	72964	318.0	311.6	6.4	0.700	0.063	N	N	8.51	....	....	
285	75096	383.2	378.4	4.8	0.437	0.108	N	T	13.60	....	....	
286	106871	402.4	....	....	0.308	0.048	N	T	5.92	....	....	
287	108533	418.0	416.0	2.0	0.377	0.067	N	N	....	....	....	
288	111327	389.4	370.4	19.0	0.082	0.050	N	N	12.25	....	....	
289	113627	554.4	545.2	9.2	0.164	0.022	N	N	19.0	....	....	
290	113343	279.2	....	....	0.628	0.058	N	N	8.3	....	....	
291	116861	254.4	....	....	0.010	0.062	N	T	4.16	....	....	
292	1076	3,390.0	....	....	....	....	....	....	1,876.20	....	....	
293	60753	485.2	463.0	22.2	0.451	L	T	0.022	123.76	....	23.4	Little browning.
294	64008	596.6	570.6	26.0	0.978	0.036	T	0.08	231.68	N	52.2	Slight browning.
295	64559	781.2	772.6	8.6	0.833	0.121	T	N	359.73	....	....	Blackening.
296	67973	271.0	260.5	10.5	0.036	0.127	N	N	3.60	101.0	3.5	Do.
297	68617	353.6	350.0	3.6	0.060	0.096	T	T	23.46	N	42.3	Slight darkening.
298	69625	1,440.4	1,408.0	32.4	1.292	0.024	N	0.009	728.92	80.0	167.5	Browning.
299	69857	283.6	281.6	2.0	0.075	0.030	N	N	31.97	N	26.0	Little darkening.
300	80060	263.2	....	T	0.066	0.062	0.058	N	22.27	10.1	9.4	
301	85906	807.0	790.4	16.6	0.290	0.101	N	N	357.69	....	....	Little browning.
302	86306	310.8	....	T	0.164	0.009	N	N	46.63	....	....	
303	91192	790.4	759.0	31.4	1.009	0.005	N	0.009	10.94	....	....	
304	92450	253.4	....	T	0.002	L	0.147	N	2.97	....	....	
305	93693	762.0	717.4	44.6	0.520	0.026	0.012	0.008	162.5	N	400.0	

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	Chlorine.	Hardness. Permanent.	Temporary.	Behavior of residue on ignition, and remarks.
306	94707	803.6	746.3	57.3	1.312	0.159	0.2	0.004	140.2	N	497.6	Browning.
307	105444	268.6	265.6	3.0	T	T	L	N	1.47	----	----	
308	106337	226.8	225.2	1.6	0.120	0.034	T	N	19.8	----	----	Darkening.
309	106814	824.4	----	----	0.012	0.012	N	T	265.6	----	----	Evolution of hydrochloric acid.
310	108254	275.6	259.2	16.4	0.275	0.005	T	N	14.77	----	----	
311	115144	225.6	----	----	0.002	0.026	T	L	1.48	----	----	
312	117520	2,266.0	----	----	1.174	0.048	N	N	1,077.9	----	----	
313	114821	1,243.6	1,176.4	67.2	1.509	0.265	T	T	599.01	----	----	
314	116862	595.2	----	----	1.606	0.193	L	N	181.86	----	----	
315	117102	308.8	----	----	0.236	0.014	N	N	4.66	----	----	
316	44380	399.8	348.2	51.6	0.004	0.004	N	N	20.0	----	----	
317	57372	381.7	332.0	49.7	0.015	0.006	N	N	7.87	----	----	
318	59533	429.6	400.4	29.2	0.004	0.018	N	N	48.88	----	110.9	
319	59580	442.4	410.4	32.0	0.004	0.019	T	T	24.85	----	102.5	
320	61809	371.0	350.6	20.4	0.035	0.013	N	N	11.28	----	101.7	
321	65576	273.6	271.1	2.5	0.030	0.024	N	N	26.40	----	21.3	Little blackening.
322	67694	4,938.0	----	----	0.190	0.032	T	N	1,095.5	446.0	234.1	Evolution of hydrochloric acid.
323	67895	382.1	362.1	20.0	0.007	0.016	N	T	13.35	----	88.3	
324	68170	242.8	228.0	14.8	0.157	0.045	N	N	4.54	N	111.0	
325	68454	678.8	670.8	8.0	0.039	0.060	N	N	207.0	N	57.0	Slight darkening.
326	68960	197.2	193.4	3.8	0.111	0.026	N	N	15.71	N	7.2	Slight blackening.
327	69291	724.8	700.4	24.4	0.227	0.055	N	N	147.46	N	32.0	
328	69815	2,383.2	2,359.2	24.0	0.172	0.042	N	T	1,139.1	133.4	97.6	Slight browning.
329	70116	435.6	429.2	6.4	0.007	0.014	N	N	44.31	N	96.0	
330	71619	320.4	----	T	0.050	0.013	T	N	13.95	N	12.0	
331	72086	1,022.4	1,004.8	17.6	0.1255	0.029	N	N	345.62	N	73.8	

332	72529	1,455.6	1,418.8	36.8	0.077	0.021	T	T	533.00	76.4	160.1	Sample after 18 hours' pumping test.
333	72622	228.8	223.2	5.6	0.183	0.019	T	N	4.07	N	112.0	
334	72622	191.6	185.2	6.4	0.005	0.017	T	N	8.15	10.3	136.0	
335	72622	380.4	372.0	8.4	0.869	0.061	1.130	0.202	8.93	N	252.0	
336	74671	199.6	186.0	13.6	0.002	0.021	T	N	1.65	-----	-----	
337	74672	396.4	347.2	49.2	0.736	0.108	T	N	14.84	-----	-----	Blackening.
338	74673	377.2	363.0	14.2	0.990	0.024	T	T	1.96	-----	-----	
339	74674	252.0	231.6	20.4	0.009	0.009	T	N	3.40	-----	-----	Little blackening.
340	74675	696.4	629.2	67.2	1.105	0.217	T	N	143.29	-----	-----	Brownish yellow color. Little browning.
341	117455	232.0	-----	-----	0.007	0.012	L	0.008	4.65	-----	-----	
342	117570	303.2	-----	-----	0.021	0.031	4.89	0.006	14.0	-----	-----	
343	80594	1,071.6	1,061.2	10.4	0.046	0.025	T	N	323.52	-----	-----	
344	80095	3,580.8	3,573.6	7.2	0.026	0.043	0.033	0.004	1,970.29	800.0	10.0	Sample taken after 3 hours of pumping at 35 liters per minute.
345	86832	278.6	274.4	4.2	0.005	0.046	N	N	34.61	-----	-----	
346	86881	395.0	366.6	28.4	0.014	0.021	N	N	12.5	-----	-----	
347	86881	452.2	-----	T	0.034	0.026	N	0.002	28.36	-----	-----	
348	87525	406.4	406.0	0.4	0.007	0.021	N	N	16.66	-----	-----	Sample taken after 6 hours of continuous pumping.
349	88593	659.6	649.8	9.8	0.009	0.009	N	N	32.5	-----	-----	
350	88594	438.2	426.0	12.2	0.019	0.009	N	N	27.0	-----	-----	
351	89163	3,370.6	3,071.0	299.6	0.192	0.070	T	N	1,668.30	-----	-----	Slight blackening and evolution of hydrochloric acid.
352	94089	439.5	394.1	45.4	0.013	0.015	T	0.02	31.49	N	289.5	
353	93776	196.0	174.7	21.3	0.010	0.059	1.000	0.0001	8.9	N	92.0	
354	94640	729.3	629.3	100.0	0.012	0.009	N	0.050	169.5	58.5	190.3	
355	96857	465.5	306.2	159.3	0.109	0.049	0.003	0.120	83.0	142.7	L	Brownish white.
356	97143	232.3	196.2	36.1	N	T	0.004	0.036	7.0	-----	-----	White.
357	97863	336.6	1.2	15.4	0.652	0.217	T	0.360	3.92	-----	-----	
358	97864	341.8	333.6	8.2	0.012	0.024	0.209	0.098	4.90	-----	-----	
359	97869	367.4	-----	T	0.350	0.090	0.169	T	4.90	-----	-----	
360	98157	606.8	582.4	24.4	0.024	0.026	1.932	0.066	60.78	-----	-----	

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as—				Chlorine.	Hardness.		Behavior of residue on ignition, and remarks.
					Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.		Permanent.	Temporary.	
361	98991	2,422.6	2,322.8	99.8	2.333	0.092	T	T	1,127.45	....	....	Slight blackening and evolution of hydrochloric acid.
362	99331	606.4	603.4	3.0	0.150	0.038	N	N	148.04	....	....	
363	99488	409.4	....	....	0.205	0.078	11.323	0.036	70.58	....	....	
364	101739	1,107.2	1,102.2	5.0	0.990	0.459	N	N	305.88	....	....	
365	101922	614.6	....	....	0.178	0.087	T	T	151.96	....	....	
366	104044	1,073.2	1,063.0	10.2	0.8211	0.253	T	T	296.07	....	....	
367	104599	358.0	330.2	27.8	0.024	0.046	E	0.016	42.15	....	....	
368	104529	626.6	612.6	14.0	0.113	0.057	T	N	110.78	....	....	
369	105142	876.2	865.4	10.8	0.019	0.062	T	T	247.00	....	....	Little blackening.
370	105271	164.2	157.8	6.4	0.014	0.038	0.117	N	2.94	....	....	Do.
371	105638	772.6	755.6	17.0	0.055	0.026	T	T	175.5	....	....	
372	106255	413.4	390.6	22.8	0.024	0.019	T	N	6.4	....	....	
373	107040	1,502.6	....	....	0.130	0.009	T	T	....	....	....	Evolution of hydrochloric acid.
374	89828	2,745.2	2,620.6	124.6	0.147	0.299	T	N	1,386.14	....	....	Slight blackening and evolution of hydrochloric acid.
375	117683	186.0	....	....	0.012	0.027	T	T	4.0	....	....	
376	117992	229.6	....	....	0.034	0.028	0.807	T	2.95	....	....	
377	112549	470.4	436.0	34.4	0.036	0.050	N	N	63.3	....	....	
378	112673	460.8	....	....	0.017	0.050	T	0.016	62.3	....	....	
379	113818	456.80	434.00	22.80	0.019	0.014	T	0.009	35.5	....	....	
380	115973	1,186.0	....	....	0.425	0.072	N	0.062	23.8	....	....	
381	117571	1,341.2	....	....	0.444	0.038	L	T	26.0	....	....	
382	116975	318.8	....	....	0.007	0.012	N	N	13.2	....	....	
383	114443	254.8	234.0	20.8	0.065	0.043	T	N	69.3	....	....	
384	115193	316.8	....	....	0.077	0.038	N	N	58.9	....	....	

385	116336	1,089.6			0.149	0.021	N	N	551.47			
386	117673	298.8			0.065	0.021	N	N	19.0			
387	112498	185.2	175.6	9.6	N	0.060	0.338	N	2.9			
388	113542	174.0	164.4	9.6	0.002	0.048	T	N	10.0			
389	112499	156.0	150.0	6.0	0.017	0.046	L	N	6.4			
390	112141	337.6	317.2	20.4	0.005	0.022	T	0.004	10.39			
391	112476	323.6			0.009	0.048	N	N	9.9			
392	112897	325.2	306.2	19.0	0.009	0.038	N	N	10.8			
393	112898	315.6	297.2	18.4	0.009	0.050	N	N	5.9			
394	113093	317.2	282.4	34.8	0.005	0.041	N	N	3.9			
395	117558	330.4			0.017	0.014	T	0.002	9.31			
396	117554	324.0			0.017	0.014	N	N	2.4			
397	117555	812.0			0.014	0.021	13.6	0.6	133.5			
398	117895	317.2			0.079	0.053	N	N	109.8			
399	114276	378.0			0.012	0.009	L	0.2	13.36			
400	112114	295.2	277.6	17.6	0.005	0.046	T	T	6.93			
401	70624	128.8	116.0	12.8	0.012	0.026	N	N	6.50			Slight blackening.
402	70355	1314.4	1237.2	77.2	0.323	0.019	T	0.717	34.51			Slight browning.
403	94869	424.0	400.8	23.2	0.376	0.087	0.027	0.003	54.53			
404	105977	993.8	982.0	11.8	3.320	0.326	U	T	147.5			Blackening and smell of burnt organic matter.
405	105993	1009.2	985.0	24.2	3.060	0.253	U	T	146.5			Do.
406	117681	1,482.4			1.510	0.555	T	T	294.0			
407	115467	1,105.6			0.227	0.01	N	0.009	368.3			
408	117451	327.6			0.041	0.017	L	L	6.37			
409	117988	328.4			0.019	0.106	0.053	0.14	42.85			
410	107944	242.8	211.8	31.0	0.256	L	T	T	6.4			Browning.
411	110866	419.2	386.8	32.4	0.517	0.069	T	T	9.5			
412	80297	344.8	334.4	10.4	0.036	0.018	0.016	N	15.64	11.46	201.34	
413	107344	340.4	320.6	19.8	0.222	0.145	L	N	9.92			Blackening and smell of acid.
414	108992	268.6		N	0.046	0.024	T	N	T			
415	110789	293.6	276.8	16.8	0.005	0.024	T	T	4.5			
416	117689	462.4			0.014	0.077	N	T	139.5			

NOTE.—Footnotes follow at the end of the table, p. 338.

TABLE VI.—*Sanitary analyses of water from deep wells*—Continued.

Tracing No.	Laboratory No.	Total solids.	Mineral matter.	Loss on ignition.	Nitrogen as— Free ammonia.	Albuminoid ammonia.	Nitrates.	Nitrites.	Chlorine.	Hardness. Permanent.	Temporary.	Behavior of residue on ignition, and remarks.
417	116713	468.8	----------	----------	0.036	0.058	T	T	81.37	----------	----------	
418	113292	106.0	----------	----------	0.007	0.024	T	N	10.5	----------	----------	
419	80287	951.2	----------	----------	0.422	0.125	N	N	146.53	6.27	7.42	
420	80450	401.2	399.4	1.8	0.017	0.033	0.030	T	31.37	28.80	171.20	
421	81495	1,045.6	1,042.8	2.8	0.398	0.071	N	N	292.14	2.31	4.62	Blackening.
422	83798	992.6	973.6	19.0	0.367	0.041	T	N	250.00	----------	----------	Browning.
423	84983	1,816.0	1,804.2	11.8	0.380	0.0724	T	T	697.08	----------	----------	Slight blackening.
424	84646	355.0	352.6	2.4	0.410	0.126	N	N	10.87	----------	----------	Slight browning.
425	87523	399.8	----------	L	0.227	0.101	T	0.414	10.98	----------	----------	Do.
426	87526	525.2	523.8	1.4	3.671	0.229	N	T	27.84	----------	----------	Do.
427	96819	993.5	847.8	145.7	0.143	0.517	0.004	0.40	245.0	136.3	72.90	
428	105742	489.8	473.0	16.8	0.012	0.031	1.2	T	59.8	----------	----------	
429	113237	463.6	418.4	45.2	N	0.017	0.875	N	27.5	----------	----------	
430	99418	1,103.8	1,054.4	49.4	0.809	0.386	N	N	476.47	----------	----------	Blackening and smell of organic matter.[g]
431	99418	635.6	615.4	20.2	0.017	0.075	0.374	N	194.11	----------	----------	Little browning.

[a] Sample of water from stratum at from 10 to 12 meters. Well 218.

[b] The sample was received in a sealed and sterilized bottle. Color of water was too dark for quantitative determination of nitrates and nitrites.

[c] This well was originally 243.8 meters deep, but gave only brackish water at depths greater than 60.9 meters.

[d] The well was deepened from 45.7 to 175.2 meters; water was struck at 166 meters.

[e] Submitted by the Bureau of Supply.

[f] After five hours of pumping at 75 liters per minute.

[g] Water came in demijohn that smelled strongly of native wine. The container was not clean, and interpretation of the analytical results might be misleading.

The high chlorine content is one of the most notable general features of Philippine artesian waters. This does not necessarily indicate sewage pollution, but rather seepage from the ocean or contact with some underground salt deposits or impregnated rocks. The water from some of the artesian wells has been found to be too salty to drink.

The high free ammonia content of certain wells, as for example those in the towns of Iloilo, Santa Barbara, and Jaro, Iloilo Province, is especially interesting. These wells are from 60 to 175 meters deep, and are cased to the bottom. They probably owe their abnormal ammonia content to the peculiar nature of the strata through which they pass. According to W. E. Pratt of the Bureau of Science:

> The wells at Iloilo are sunk through estuarine deposits which are high in organic matter resulting both from plant and animal remains in the sediments themselves and from included remains of organisms that lived in the salt or brackish water in which the beds were laid down. The character of the water itself is likewise transmitted to the sediments through saturation during deposition and preservation by subsequently deposited overlying strata. Silts with considerable contents of humus, soils, carbonaceous clays, shales, and sands impregnated with salts from sea water are the prominent members of the formation. Artesian water is obtained from lenses of sand or fine gravel in the general formation. It is uniformly salt in the low-lying part of the province at a depth greater than approximately 165 meters.

A flowing well is to be preferred because of the decreased danger of pollution. It is an established fact that bacteria cannot be entirely removed from deep wells by pumping; on the other hand, flowing artesian wells from deep strata are practically sterile. The pressure in flowing wells tends to prevent surface seepage. In a study covering 22 flowing and 12 pumping artesian wells, Barber [10] of the Bureau of Science found that the best pumping well showed more bacteria per cubic centimeter than did the poorest flowing well reported. He says in conclusion:

> the waters from the flowing wells show a remarkably high degree of bacterial purity and may be regarded as free from pollution by pathogenic bacteria. The pumping wells show a much lower degree of bacterial purity, although it is unlikely that any of them were polluted to a dangerous degree at the time of examination. These wells should be examined occasionally—especially during the prevalence of water-borne diseases—since they cannot be regarded as absolutely safe from pollution.

In general, artesian water has been found quite satisfactory, both from the chemical and biological points of view, and in

[10] *This Journal, Sec. B* (1913), **8**, 458.

many instances where the quality left something to be desired the water was so much better than any other available supply that its use has been permitted.

POLLUTION OF WATER SUPPLIES

All available data emphasize the difficulty in obtaining pure water in the Philippines and in keeping it free from contamination. Edwards, in a biological study of Philippine waters,[11] found 53 per cent of all the samples submitted dangerously polluted, and confirmed the generally accepted conclusion that all water used for drinking purposes should be boiled. Even where pure water is obtainable, the methods of handling and storing[12] are often such that the water is unfit to drink.

At Antipolo, 25 kilometers from Manila, is the shrine of Nuestra Señora de la Paz y Buen Viaje, to which people make pilgrimages in large numbers. Sometimes as many as 10,000 persons visit the shrine in one day, and they have to be accommodated in the small town of Antipolo, which has no facilities for meeting the sanitary needs of such a multitude. To quote again from the report of the Bureau of Health.[13]

> One of the greatest dangers connected with the pilgrimage is the fact that it is customary after visiting the Virgin to bathe in the river which flows by the town. The water for drinking and other domestic purposes is obtained from this river at a point below where the bathing takes place. In order to supply a better drinking water an artesian well has been dug. Unfortunately, the quality of the water is not of the very best, and on account of a slightly disagreeable taste it is almost completely eschewed by the people, who still continue to obtain their water supply from the river. Another source of great danger is the lack of proper facilities for the disposal of human excrements. The sanitary facilities of the town are not nearly sufficient to meet the demands of the great number of persons who go there.

The state of affairs in this small town is rather significant. The municipality has not sufficient funds to provide a system of sewage disposal adequate for the needs of its own inhabitants.

For a long time Manila had the highest infant mortality rate of any city on record. In this connection Musgrave says:[14]

> The next most important faulty custom consists in the dilution of milk compounds with unsafe water. In our investigation of the causes

[11] *Ibid.* (1908), **2**, 21.

[12] For an account of the mode of living and the customs of the Filipinos, especially with reference to the problem of water supply, see *This Journal, Sec. B* (1909), **4**, 211.

[13] *Annual Rep. P. I. Bur. Hlth.* (1912–13), 62.

[14] *This Journal, Sec. B* (1913), **8**, 465.

of death of 300 babies, it is found that tap water, either with or without boiling, is used as a diluent in most instances. As a majority of the houses of these people are at considerable distances from the nearest faucet, the water is carted by water carriers and kept in earthenware jars or other vessels under the most unsanitary conditions; in many instances whatever safety might be secured by boiling the water is destroyed by the subsequent manipulations and care of the water and by the methods employed in making the dilutions of the milk mixtures.

WATER-BORNE DISEASES

The average Filipino is undernourished and underdeveloped. From 80 to 96 per cent [15] of the native population suffers from intestinal parasites. Just how great a rôle impure water has played in bringing about this state of affairs has not been demonstrated, but it certainly has been one of the great factors. Vital statistics indicate that the death rate from intestinal diseases was three times as great before the installation of the new Manila water supply (1908) as at present. In periods of continued drought when it became necessary temporarily to use water from Mariquina River to supplement the regular supply, there was in each case a sudden increase in the death rate.[16]

Contrary to experience in the United States, water-borne diseases are more prevalent in the Philippines during the rainy season [17] than at any other time, probably due to the washing of accumulated surface débris and fæcal matter into the water courses.

The three most important "water-borne" diseases are typhoid, cholera, and entamœbic dysentery, although water probably is not the most important medium for their transmission.

Typhoid.—Typhoid fever is very common and widespread in temperate and tropical countries. Chamberlain [18] and Heiser [19] have written concerning the prevalence and nature of typhoid in the Philippines. It appears to be distributed equally throughout the year. Chamberlain reported the death rate in Manila from typhoid as 36.8 per 100,000. This rate was exceeded only by those of cities which were notorious for high typhoid rates. Chamberlain points out that—

The water supplies are almost universally bad, the proper disposal of excreta is almost entirely neglected, the crowding in the habitations and

[15] *Ibid.* (1909), 4, 261.
[16] *Annual Rep. P. I. Bur. Hlth.* (1912), 4, 46.
[17] *Ibid.* (1911–12), 47.
[18] *This Journal, Sec. B* (1911), 6, 299.
[19] *Ibid.* (1912), 7, 115.

the native manner of eating favor contact infection. Yet, in spite of these unfavorable conditions, there is little evidence that severe and destructive epidemics of typhoid fever occur among the Filipinos. * * *

Widal reactions performed on the blood of 591 healthy Filipinos suggest a comparatively recent attack of typhoid in about 6 per cent of adults, but do not indicate that the disease is prevalent in childhood.

According to Nichols [20] typhoid is endemic in Samar, Leyte, and Iloilo.

Cholera.—In spite of the frequent and terrible outbreaks of cholera in the Philippines in the past, it is still an open question whether or not the disease is endemic. For the last few years, the disease has been practically absent. It is significant to note that the year from July 1,1912, to June 30, 1913, was the first on record during which, so far as known, there was not a single case of cholera in the Islands.[21]

That cholera vibrios will live in water is a well-established fact. They are, however, very readily destroyed. Schöbl [22] of the Bureau of Science, who studied the vitality of cholera vibrios in Manila water, kept the organism alive at room temperature (25° to 27°) in sterile water for seven days, in unsterilized tap water for fifty-six days, and in sea water for one hundred six days. The inoculations were made with fæces. The experiments with tap water were especially significant, since they showed that the organisms may persist in ordinary water for a long time. When the amounts of fæces used for inoculation were small, the vibrio remained alive longer than when the amounts were increased, indicating that highly polluted water is less favorable to the existence of the organism than is the ordinary tap water of Manila. At no time, even during the worst cholera epidemics, were cholera vibrios detected in the Manila city water supply.

Entamœbic dysentery.—Entamœbic dysentery has frequently been considered to be a water-borne disease, but Walker [23] has shown that entamœbæ do not multiply in water and if present are there only in the encysted form due to direct contamination by human fæces.

A large percentage of the Philippine waters examined at the Bureau of Science contains amœbæ. The Manila water supply

[20] *Ibid.* (1909), 4, 282.

[21] *Annual Rep. P. I. Bur. Hlth.* (1912–13), 110.

[22] Extract from a paper read before the Manila Medical Association, April, 1914.

[23] *This Journal, Sec. B* (1911), 6, 259; Walker and Sellards, *ibid.* (1913), 8, 253.

has practically never been free from them. However, that the amœbæ ordinarily growing in water cause dysentery in man has been disproved.[24]

PURIFICATION OF WATER SUPPLIES

As all natural waters in the Philippines, with the probable exception of most flowing artesian wells, contain various organisms, it is evident that, to be perfectly safe, water must be sterilized or at least so treated that harmful organisms will be destroyed.

Distillation.—The Americans soon introduced the use of distilled water for drinking purposes, both the military and civil governments operating their own distilling plants. The latter furnishes the public with drinking water at the rate of 1 centavo (5 mills U. S. currency) per liter. Recently, distilled water has been largely replaced by water from artesian wells known to be pure.

Boiling.—Boiling is perhaps the simplest and most universal safeguard in so far as contamination of water due to living organisms is concerned, and is necessary in the Philippines in localities where distilled water or water procured directly from sources of known purity is not available; but general information concerning the subject is not widespread, and the cost of fuel is so high and the cooking facilities in the average home are so poor that in some instances it is difficult for families to cook their food. The peculiar taste of boiled water, superstitions regarding its harmful character, and the lack of a comprehension of the purpose of the boiling militate against its use.

Filtration.—So far very little work has been done in the Philippines on the filtration of public water supplies, owing to the urgency of other work and to the scarcity of large water-supply installations. Filtration on a large scale has not yet been attempted, but the need of some adequate system of purification has been felt in the city of Manila, and it is probably only a question of time before some filtration system will be installed.

Ultra-violet light.—Preliminary experiments on sterilization with ultra-violet light have been very encouraging, and further investigations are contemplated with the sterilizing outfit recently installed at the Bureau of Science.

Copper sulphate.—The purification of the Manila water supply with copper sulphate was investigated in 1906 and again during an interruption of the service of the Montalban water supply in

[24] Walker, *loc. cit.*

1912. It was demonstrated in the laboratory that, in order to safeguard the supply against cholera vibrios, the addition of copper sulphate in the ratio of 1 part per 150,000 of water (a strength considered undesirable for drinking purposes), acting over a period of four hours, would be required.

Calcium hypochlorite.—During the past few months the water entering the Manila city main has been treated with an amount of calcium hypochlorite representing an addition of from 1 part of available chlorine in 3,000,000 parts of water to 1 part in 1,200,000. Unfortunately, the city is using unfiltered surface water, leaving the ultimate success of chlorination in considerable doubt. A rather extensive investigation of the purification of Manila water is being carried on, and is to be reported more fully later. The water is chlorinated at the reservoir just as it enters the main leading to the city. At San Juan Bridge, about 3 kilometers below the chlorination station, the water shows a much lower bacterial count than the water entering the reservoir from the dam or pumped into the old Spanish reservoir from Mariquina River at Santolan, indicating a high efficiency for the chlorination process.

The velocity in the city main is relatively low. The mains were designed for a daily consumption of 25,000,000 gallons which would produce a velocity of almost 1 meter per second. As they usually carry less than half that amount, there is insufficient scouring of the pipe to carry off sediment. Considerable quantities of fragments of leaves, wood, and other organic matter are carried by the water into the mains, where they lodge and form culture media for bacterial growth. There seems to be no doubt that bacteria multiply rapidly in the pipes within the city, for the bacterial count from the taps at the Bureau of Science is usually higher than that at either San Juan Bridge or even at the intake of the city mains. This is further substantiated by the significant fact that, although bacteria of the *B. coli* group were usually absent in 2 cubic centimeter samples of water taken daily for a period of several weeks at San Juan Bridge, they are generally found in samples taken from the taps at the Bureau of Science. The forced flushing of the mains with sufficient water to scour the pipes would be beneficial, but this measure is impracticable during the dry months, when the amount of water available is so small that it is either inadequate or barely sufficient for the city's needs.

WATER FOR INDUSTRIAL PURPOSES

In the Philippines, where manufacturing industries are for the most part still in their infancy, little or no attention was formerly paid to the question of the quality of water for industrial purposes. However, there is a growing demand for systematic study of industrial water supplies. The problem of finding water, not only in sufficient quantity but also of suitable quality, is one of the large factors in the determination of the ultimate success or failure of many of our commercial enterprises. This is particularly true in the Philippines, where there is an excessive amount of salt in many inland waters. The rapid corrosion of metals, probably accelerated by the high temperature and humidity, also introduces many factors with which manufacturers elsewhere generally do not have to contend.

The qualities most desired in water for industrial purposes are, in general, softness and freedom from suspended matter; however, the suitability of any water depends, in a large measure, on the industry for which it is to be used.

Very soft water; water containing sulphuric acid, free carbon dioxide, or over 200 parts per million of chlorine; and acid waters in general are corrosive, especially when used in boilers. Water with over 100 parts per million of chlorine generally proves injurious to plants. Water containing sulphuric acid is not adapted to sugar manufacture. Hydrogen sulphide is poisonous, and renders water generally unfit for drinking or for industrial use; silica is objectionable in boiler water when present in more than 15 parts per million; and a high nitrate content spoils water for brewing, fermentation, or sugar refining. Alkaline salts tend to make water unfit for boiler supply, irrigation, or sugar refining; more than a trace of ammonia interferes in brewing, fermentation, or starch industries; and iron and manganese are nearly always objectionable, even in small quantities.

Water which is entirely unfitted for one enterprise may be excellent for another. Waters containing sodium chloride are undesirable for soap making, yet are sometimes decidedly advantageous in brewing. Hard waters entirely unsuited for laundry or boiler use may be quite suitable for irrigation purposes. Waters containing calcium and magnesium sulphate, adaptable to brewing, are undesirable for soap making or boiler use.

Technical or commercial analyses of waters are made to determine their suitability for making steam, for manufacturing, and

for domestic or laundry and irrigation purposes. By furnishing analytical data with regard to the waters of the Philippines, we hope to give information concerning the suitability of various waters for industrial purposes, the cause of difficulties arising from their use, and the possibility of improving them.

The ordinary analytical methods used in the examination of water permit of accurate determinations of the total solid matter and of the elements and radicals present. The treatment of the total solid matter with a small amount of water sufficient to dissolve the alkali salts will more or less approximately separate the scale-forming from the nonscale-forming ingredients. To go further than this in an expression of the salts and compounds present in water is largely a matter of conjecture.[25] Table VII contains technical analyses of waters throughout the Philippine Islands.[26]

[25] Cf. Hendrixson, *U. S. Geol. Surv., Water-Supply Paper* (1912), **293**, 136.

[26] Sanitary analyses of water from deep wells are included in Table VI.

TABLE VII.—*Technical analyses of Philippine waters.*[a]

[L=little; N=nil; T=trace; U=undetermined.]

(Numbers give parts per million.)

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
1	54908	January, 1909	Albay, Legaspi	Submitted by Manila R. R. Co		289.2	270.8
2	83789	October, 1910	Albay	Libon well		1,620.1	1,564.6
3	61024	September, 1908	do	Coal Harbor, Cacraray Island	Alkaline	400.4	305.6
4	86551	February, 1911	Agusan, Butuan	Well 223		1,336.8	1,291.2
5	107343	September, 1912	Ambos Camarines, San Jose	Well 443	Neutral	284.4	268.2
6	78712	May, 1910	Batangas, Balayan	Well 164; 114.3 meters deep; flows 227 liters per minute.	Alkaline	395.2	389.6
7	79221	June, 1910	do	No. 175; 114.3 meters deep; flows 568 liters per minute.	do	378.4	349.6
8	82704	September, 1910	Batangas	Lipa quarry	do	243.2	232.2
9	84437	November, 1910	do	Spring, Taal	do	691.6	664.4
10	84438	do	do	do	do	718.4	694.8
11	84439	do	do	do	do	774.8	747.6
12	84440	do	do	do	do	693.6	680.4
13	84441	do	do	Pansipit River	do	1,463.2	1,432.8
14	67333	March, 1909	do	Well at Batangas	do	380.7	364.7
15	2488		do	Taal Lake	do	1,716.0	1,484.0
16	93292	October, 1911	Batangas, Nasugbu	Well 307	do	640.2	639.4
17	95430	February, 1912	do	Well 339	do	646.7	571.8
18	98447	March, 1912	Batangas, Balayan, Calatagan	Well 354		1,276.2	1,274.4
19	105125	July, 1912	Batangas, Lipa	Well 420	Neutral	295.4	273.4
20	109934	December, 1912	Batangas, Tanauan	Well 469	Alkaline	276.0	269.0
21	108462	October, 1912	do	Well 436	do	325.2	316.0
22	1006a	October, 1902	Benguet	South Spring, Twin Peaks	do	294.0	
23	1006b	do	do	Gorge above Bued River	do	1,556.0	

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
24	1006c	Octobor 1902	Benguet	Stream near 1006a	Alkaline	320.0	
25	1006d	do	do	North Spring, Twin Peaks	do	271.0	
26	1006e	November, 1902	do	Spring 4.8 kilometers above Twin Peaks.	do	347.0	
27	1006f	do	do	Stream 4.8 kilometers above Twin Peaks.	do	341.0	
28	1006g	do	do	River 1.6 kilometers above Twin Peaks.	do	1,447.0	
29	1006h	do	do	Stream, Camp 5	do	563.0	
30	1006i	do	do	Right bank opposite Camp 5	do	355.0	
31	1006j	do	do	Left bank below Camp 5	do	417.0	
32	1006k	do	do	Large spring near Baguio, source of Bued River.	Slightly acid	24.0	
33	1006l	do	do	Spring 0.8 kilometer east of hospital.	Neutral	64.0	
34	1006m	do	do	Large spring near Baguio, source of Bued River.	Slightly acid	50.0	
35	90142	July, 1911	do	Mine water, Headwaters mine	Neutral	876.6	862.0
36		October, 1911	Benguet, Daklan	From "Lower Springs"	Alkaline	311.8	304.8
37	99591	May, 1912	Benguet, Camp John Hay, Baguio.	Iron spring	Acid	90.2	
38	99591	do	do	Big spring	do	62.6	
39	80289	July, 1910	Bohol, Tagbilaran	Well 167; 17 meters deep; flows 227 liters per minute.	Alkaline	2,146.8	2,144.4
40	83330	October, 1910	Bohol, Sauang, Loboc	Well	do	464.0	449.2
41	83331	do	Bohol, Villaflor, Loboc	do	do	565.2	514.4
42	83717	do	Bohol, Tagbilaran	Well 2; 210 meters deep; pumps 227 liters per minute.	do	2,547.8	2,331.3
43	83743	do	Bohol, Laya, Baclayon	Well	do	1,458.2	1,401.2

44	91226	September, 1911	Bohol, Mansasa-Tagbilaran	do		1,603.6	1,552.2
45	93928	December, 1911	Bohol, Loay	Spring	Alkaline	346.0	320.3
46	93941	do	Bohol, Tagbilaran, Cogon	Well	Neutral	426.8	385.8
47	94257	do	Bohol, Dawis, Bingag	do	Slightly alkaline	331.0	307.4
48	96694	February, 1912	Bohol, Panglao, Tognan	do	Alkaline	702.3	576.8
49	97168	do	Bohol, Tubigan	Spring	Neutral	265.7	248.5
50	97865	March, 1912	Bohol, Duero	do	Alkaline	249.8	
51	104914	July, 1912	Bohol, Tubigan	do	do	321.0	314.0
52	46442	July, 1907	Bulacan, Bigaa	Well		397.9	391.0
53	47956	August, 1907	do	do		402.7	400.3
54	47957	do	Bulacan, Malolos	Provincial well		610.9	599.6
55	49775	September, 1907	Bulacan, Bocaue	Driven well; 127.7 meters deep		262.6	245.5
56	52562	November, 1907	Bulacan, Meycauayan	Well		258.2	234.2
57	53508	December, 1907	do	do		246.8	236.6
58	54721	January, 1908	Bulacan, Marilao	do		220.4	219.8
59	56949	February, 1908	Bulacan, Polo	Driven well		231.1	230.8
60	56965	March, 1908	do			214.8	197.4
61	57479	do	do			216.8	194.4
62	58273	April, 1908	Bulacan, Obando	Well	Alkaline	229.2	208.8
63	78825	June, 1910	Bulacan, Calumpit	Well 162; 124.3 meters deep; flows 64 liters per minute.	do	343.4	341.0
64	85759	January, 1911	Bulacan, Baliuag	Well 224; 152.4 meters deep; flows 95 liters per minute.	do	1,011.2	998.0
65	87524	May, 1911	do	Well 246; 118.8 meters deep; flows 719 liters per minute.	do	1,095.4	1,089.2
66	89432	June, 1911	do	Well 279; 163.3 meters deep; flows 57 liters per minute.		1,049.2	
67	42794	April, 1907	Bulacan, Malolos	Municipal well; 56.3 meters deep		970.6	937.4
68	43533	May, 1907	Bulacan, Bulacan	Municipal well		700.2	684.0
69	44052	do	Bulacan, Guiguinto	Well		1,391.8	1,360.6
70	97049	February, 1912	Bulacan, Baliuag	Well 345	Alkaline	1,114.3	1,081.8
71	97173	do	Bulacan, Sibul	Estero of Sibul	Slightly alkaline	301.2	284.1
72	79174	do	do	Estero of Sibul (No. 2)	do	413.2	390.9

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
73	98529	March, 1912	Bulacan, Baliuag	Well 364	Alkaline	896.4	891.0
74	102056	June, 1912	Bulacan, Santa Maria	Well 389	do	280.0	S
75	105141	July, 1912	Bulacan, Angat	Well 400	do	1,339.6	1,319.0
76	109843	December, 1912	Bulacan, Norzagaray	Well 426	do	821.6	811.2
77	79649	August, 1910	Capiz, Capiz	Well 146; 306.3 meters deep; pumps 76 liters per minute.	do	2,873.4	2,871.8
78	87656	May, 1911	do	Well	do	1,722.8	1,694.4
79	58645	May, 1908	Cavite, Noveleta	do	do	868.4	836.4
80	58765	June, 1908	do	do	do	796.4	770.0
81	74811	January, 1910	Cavite, Cavite	Well 131; 160 meters deep; pumps 189 liters per minute.	Neutral	497.8	487.6
82	75304	January, 1909	Cavite, Rosario	Well 135; 27.4 meters deep; flows 42 liters per minute.	do	353.6	334.0
83	77565	April, 1910	Cavite, Naic	Well 147; 56.9 meters deep; pumps 57 liters per minute with hand pump.	Slightly alkaline	354.8	342.0
84	78903	June, 1910	Cavite, Caridad	Well 165; 135.9 meters deep; pumps 227 liters per minute.	Alkaline	512.4	510.0
85	80288	July, 1910	Cavite, Imus	Well 180; 71.0 meters deep; pumps 151 liters per minute.	do	380.8	
86	80790	August, 1910	Cavite, San Roque	Well 182; 184.4 meters deep; flows 113.5 liters at low tide and 151 at high tide.	do	514.6	
87	83352	October, 1910	Cavite, Imus	Well 215; 76.2 meters deep; flows 26 liters per minute.	do	396.8	381.0
88	83950	November, 1910	do	Well	do	409.0	388.2
89	83799	October, 1910	Cavite, Cavite	Well 201; 182.8 meters deep; pumps 227 liters per minute.	do	500.8	499.4

90	88873	June, 1911	Cavite, Santa Cruz de Malabon	Well 274; 54.8 meters deep; pumps 68 liters per minute.	do	396.2	382.4
91	88878	do	do	Well 289; 76.5 meters deep; pumps 76 liters per minute.	do	390.6	378.0
92	89998	August, 1911	Cavite, Santa Cruz	Well 313; 92.3 meters deep; pumps 113.5 liters per minute.		347.6	339.2
93	107605	October, 1912	Cavite, Santa Cruz de Malabon	Well 433	Alkaline	415.8	387.6
94	109674	December, 1912	do	Well 457	do	410.0	393.6
95	110193	do	do	Well 474	do	367.4	357.0
96	71504	September, 1909	Cebu, Cebu	Municipal well	do	454.4	446.0
97	71504	do	Cebu	Customhouse well	do	604.4	602.8
98	91643	August, 1911	Cebu, Mabolo	Well 299; 187 meters deep; pumps 378.5 liters per minute.	do	338.2	
99	20914	August, 1905	Cebu, Cebu	Well; water from well at depth of 28.9 meters.	do	1,499.0	
100	28301	March, 1906	do	Well; water from well at depth of 28.9 meters.		1,629.0	1,577.0
101	29455	April, 1906	Cebu, Cauit Island	Artesian well; water from well at depth of 76.2 meters.		2,583.8	2,515.8
102	31293	May, 1906	do	Quarantine station		4,443.5	4,394.5
103	36976	October, 1906	Cebu, Cebu	Guadalupe River	Acid	485.3	763.0
104	39089	January, 1907	do		Alkaline	391.6	387.4
105	51541	November, 1907	Cebu, Mandaue	Spring		386.0	371.8
106	94003	November, 1911	Cebu	At proposed military reservation. From high falls of Lajog Creek.	Alkaline	218.5	168.7
107	94003	do	do	Proposed military reservation. Smaller falls 1.2 kilometers above high falls.	do	209.0	160.0
108	94003	do	do	Proposed military reservation. 1.2 kilometers above smaller falls.	do	175.3	121.6
109	94003	do	do	do.[g]	do	245.0	172.7

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
110	96990	February, 1912	Cebu, Mabolo Estate	Well 327	Alkaline	376.0	326.5
111	97268	April, 1912	Cebu, Mabolo Estate	do	do	318.2	310.0
112	99397	do	Cebu, Argao	Well 376	do	521.2	520.8
113	58254	May, 1908	Corregidor	Well	do	664.0	581.2
114	88400	June, 1911	Grande Island	Well, Fort Wint; 106.6 meters below mean tide, flows 265 liters per minute.	do	4,151.8	3,209.4
115	88400	do	do	Well 4, Fort Wint	do	295.2	278.2
116	90607	August, 1911	Ilocos Sur, Vigan	Well at college		737.8	735.6
117	98446	March, 1912	do	Nagguiddyan Spring	Alkaline	217.0	216.0
118	110499	December, 1912	Ilocos Sur, Candon	Well 439	do	1,359.6	1,349.0
119	59352	July, 1908	Iloilo, Jaro	Well	do	892.8	874.8
120	59353	do	do	River	do	320.0	309.2
121	68657	May, 1909	Iloilo	Pototan River	do	304.4	295.6
122	68658	do	do	Passi well	do	641.2	612.4
123	68659	do	do	Jaro River	do	317.6	309.2
124	68660	do	do	Jaro well	do	1,056.4	967.6
125	74899	December, 1909	Iloilo, Jaro	Well 97; 178.3 meters deep; pumps 76 liters per minute.	do	2,898.8	2,872.0
126	75306	do	Iloilo, Santa Barbara	Well; 152.4 meters deep; flows 132 liters per minute.	do	1,202.4	1,192.0
127	85947	January, 1911	Iloilo, Pototan	Well 218; 457.2 meters deep; sample from water stratum at 12 meters.	do	631.6	
128	15676(3442)	March, 1905	Iloilo, Provisor Island	Submitted by J G. White & Co		444.2	426.1
129	15676(3443)	do	Iloilo, Nagaba	do		467.2	294.4
130	15676(3444)	do	Iloilo, Salog			472.0	292.0
131	32180	June, 1906	Iloilo, Provisor			1,757.2	1,716.4

132	35024	August, 1906	Iloilo	Jaro River at La Paz; submitted by Philippine R. R. Co.		548.1	406.6
133	35025	do	Iloilo, Jaro	Jaro River		483.5	365.0
134	94862	January, 1912	Iloilo, Janiuay	Well 308	Alkaline	8,197.5	7,950.2
135	107186	September, 1912	Iloilo, Iloilo	Well 428	Slightly alkaline	2,158.4	2,125.4
136	108062	October, 1912	do	Well 452	Alkaline	2,244.8	2,214.8
137	109063	November, 1912	do	Well 461	do	2,746.0	2,563.5
138	110053	December, 1912	do	Well 471	do	2,153.2	2,115.2
139	79009	June, 1910	Jolo	Augur Barracks	Slightly alkaline	109.2	98.0
140	58171	April, 1908	Laguna, Santa Cruz	Well		216.6	210.6
141	58240	do	do	do		217.6	187.2
142	58483	May, 1908	do	Well 1	Alkaline	220.4	193.0
143	58575	do	do	Well 2	do	452.4	378.0
144	92745	October, 1911	Laguna, Tunasan	Well 326, San Pedro; 108.2 meters deep; flows 39 liters per minute.	do	399.0	389.6
145	93063	do	Laguna, Biñang	Ordinary open well, north central part of Biñang.	do	651.2	614.4
146	93063	do	do	Ordinary open well, back yard of cockpit, north part of town.		530.4	506.6
147	93063	do	do	From rill or small spring on right bank of river north of town.	Slightly alkaline	315.4	282.0
148	93063	do	do	Ordinary open well in center of town.	Alkaline	810.6	769.8
149	93552	November, 1911	do	Well 330; 92.9 meters deep; flows 57 liters and pumps 189 liters per minute.	do	392.5	314.4
150	98927	December, 1911	Laguna	Well 336 (Biñang No. 2); 74.6 meters deep; flows 113.5 liters per minute.	do	381.9	291.3
151	107603	October, 1912	Laguna, Santa Cruz	Well 440	do	492.6	466.6
152	108464	do	Laguna, Pagsanjan	Spring 1	do	303.8	276.0

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters*[a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
153	108464	October, 1912	Laguna, Pagsanjan	Spring 2	Alkaline	301.6	
154	108464	do	do	Spring 3	do	291.0	269.2
155	110480	December, 1912	Laguna, Santa Cruz	Well 459	do	454.0	434.0
156	94767	January, 1912	Laguna, Santa Rosa	Well 341	Slightly alkaline	394.0	324.7
157	94992	do	Laguna, Cabuyao	Well 343	Alkaline	755.1	706.0
158	94993	do	do	Well 347	Slightly alkaline	350.2	300.0
159	97081	February, 1912	Laguna, San Pablo	Flowing spring	Neutral	209.5	174.8
160	97537	do	Laguna, Calamba	Well 356	Akaline	367.8	
161	68605	May, 1909	Leyte, Carigara Sawang	Well,	do	1,304.2	1,237.2
162	68197	April, 1909	Leyte, Carigara	Well, 78; 51.8 meters deep	do	1,274.4	1,241.6
163	55928	February, 1908	Manila, Engineer Island	Well, sample from depth of 36.5 meters.	do	885.2	866.0
164	55928	do	do	Well, sample from depth of 91.4 meters.		877.6	863.2
165	55928	do	do	Well, sample from depth of 128 meters.		877.2	861.6
166	55928	do	do	Well, sample from bottom of well.		874.8	861.2
167	58797	June, 1908	do	Well, Manila R. R. Co. station	Alkaline	218.4	
168	21071	September, 1905	do	Well, Insular ice plant		402.4	
169	26951	January, 1906	do	Pasig River		242.0	168.0
170	38446	December, 1906	Manila, San Lazaro	Race track	Alkaline	427.5	396.4
171	46104	July, 1907	Manila	Well, 95 Anloague; submitted by Philippine Products Co.		1,930.3	1,618.7
172	52172	November, 1907	do	Well, Manila R. R. Co. station		8,224.0	7,355.0
173	54050	December, 1907	do	do		1,796.0	1,718.8
174	15898	March, 1905	do	"Mineral water from Lanot"		436.0	320.0
175	99259	March, 1912	do	"Varadero de Manila,"	Alkaline	507.6	496.0
176		October, 1910	do	Well 2		527.0	

177	77822	April, 1910	Mindoro	Submitted by Mindoro Development Co.	Neutral	146.4	137.6
178	110865	December, 1912	Misamis, Cagayan	Well 410	Alkaline	1,446.0	1,379.2
179	79220	June, 1910	Nueva Ecija, Gapan	Well 179; 24.9 meters deep; pumps 75.5 liters per minute.	do	573.4	541.8
180	82585	September, 1910	do	Well 214; 24 meters deep; pumps 132 liters per minute.	Slightly alkaline	324.4	300.6
181	94613	January, 1912	Nueva Ecija, Cabanatuan	Well 317	do	240.0	227.5
182	48209	August, 1907	Pampanga, San Fernando	Municipal well		439.6	437.0
183	48210	do	do	Provincial well		422.6	418.0
184	48214	do	Pampanga, Mexico	Well		433.6	429.0
185	48263	do	Pampanga, Macabebe	Well; flowing 227 liters per minute.		359.0	356.4
186	48268	do	Pampanga, Guagua	Well		1,207.0	1,187.2
187	48269	do	Pampanga, Lubao	Driven well		314.8	304.0
188	48270	do	Pampanga, Bacolor	do		446.8	441.6
189	48311	do	Pampanga, Santo Tomas	do		243.8	243.0
190	48312	do	Pampanga, Minalin	do		234.2	232.8
191	108533	November, 1912	Pampanga, Candaba	Well 450	Alkaline	418.0	416.0
192	106371	September, 1912	do	Well 434	do	402.4	
193	88271	May, 1911	Pangasinan, Camp Agno Gorge	Agno River	Slightly alkaline	209.8	207.4
194	60753	October, 1908	Pangasinan, Dagupan	Well	Alkaline	485.2	463.0
195	67008	February, 1909	Pangasinan, Lingayen	Well 39; 197.5 meters deep; flows 189 liters per minute of very warm water.	do	596.6	570.6
196	68617	May, 1909	Pangasinan, Calasiao	Well 80; 48.9 meters deep: flows 189 liters per minute.	do	353.6	350.0
197	80060	July, 1910	Pangasinan, Bautista	Well 181; 74.6 meters deep; after 60 hours flowing 37.5 liters per minute.	Slightly alkaline	263.2	
198	85906	January, 1911	Pangasinan, Bayambang	Well 226; 117.3 meters deep; flows 5.5 and pumps 94.5 liters per minute.	Alkaline	807.0	790.4

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixed solids.
199	86306	February, 1911	Pangasinan, Bayambang	Well 259; 37.3 meters deep; flows 1,892 liters per minute.	Alkaline	310.8	
200	91192	August, 1911	Pangasinan, Malasiqui	Well 310; 91.4 meters deep; pumps 946 liters per minute.		790.4	759.0
201	64559	February, 1909	Pangasinan, Lingayen	Well 39	Alkaline	781.2	772.6
202	67973	April, 1909	Pangasinan, Dagupan	Well 75; 67 meters deep; flows 567.5 liters per minute.	Neutral	271.0	260.5
203	93693	November, 1911	Pangasinan, Mangaldan	Well 328; 32 meters deep; flows 284 liters per minute.	Alkaline	762.0	717.4
204	92450	October, 1911	Pangasinan, San Fabian	Well 325; 35 meters deep; flows 605.5 liters per minute.	do	253.4	253.4
205	94707	January, 1912	Pangasinan, Binmaley	Well 335	Slightly alkaline	803.6	746.3
206	105444	July, 1912	Pangasinan, San Jacinto	Well 408	Alkaline	268.6	265.6
207	106337	August, 1912	Pangasinan, Alcala	Well 415	do	226.8	225.2
208	108254	October, 1912	Pangasinan, Santo Tomas	Well 445	do	275.6	259.2
209	106814	September, 1912	Pangasinan, Sual	Well 403	do	824.4	
210	57372	March, 1908	Rizal, Fort William McKinley	Well 7; 265.7 meters deep		381.7	362.6
211	58444	May, 1908	Rizal, Sucat			535.6	458.4
212	59533	do	Rizal, Fort William McKinley	Sample from 7 wells, from 228.6 to 320 meters deep.	Alkaline	429.6	400.4
213	59580	July, 1908	Rizal, Alabang	Well 29; sample from depth of 2.7 meters.	Markedly alkaline	442.4	32.0
214	58796	June, 1908	Rizal, Caloocan		do	268.4	
215	61809	November, 1908	Rizal, Fort William McKinley	Well 8; 213.3 meters deep	Alkaline	371.00	350.60
216	65576	March, 1909	Rizal, Navotas	Well, 161 meters deep	do	273.6	271.1
217	67694	April, 1909	Rizal, Pasay	Well 45; 178.3 meters deep; pumps 568 liters per minute.		4,938.0	
218	67895	do	Rizal, Fort William McKinley	Well 9; 228.6 meters deep	Alkaline	382.1	362.1
219	68170	May, 1909	Rizal, San Mateo	Well 77; 43.8 meters deep	do	242.8	228.0

220	68454	do	Rizal, Pasay	Well; 228.6 meters deep; pumps 151 liters per minute.	do	678.8	670.8
221	68815	August, 1909	Rizal, Parañaque	Well 99; 182.8 meters deep		2,383.2	2,359.2
222	70116	September, 1909	Rizal, Fort William McKinley	Well 10; 245.3 meters deep		435.6	429.2
223	71619	do	Rizal, Caloocan	Well 105; 213.3 meters deep; flows 113.5 liters per minute.	Alkaline	320.4	
224	72086	do	Rizal, Parañaque	Well 99; 274.3 meters deep; with light flow.	do	1,022.4	1,004.8
225	72529	do	Rizal	Well 116; Polo Club, Pasay; 21.9 meters deep.		1,455.6	1,418.8
226	80095	July, 1910	Rizal, Pasig	Well 133; sample from well 268.2 meters deep, after 3 hours' pumping; pumps 38 liters per minute.	Alkaline	3,580.8	3,573.6
227	80594	August, 1910	Rizal, Pasay	Well 116; 226.4 meters deep; pumps 189 liters per minute.	do	1,071.6	1,061.2
228	86832	March, 1911	Rizal, San Pedro Macati	Well 258; flows 11 and pumps 78 liters per minute.	do	278.6	274.4
229	87525	April, 1911	Rizal, Alabang	Well 257; 302 meters deep; pumps 378.5 liters per minute.	do	406.4	406.0
230	86881	March, 1911	Rizal, Camp Gordon	Well 1; 45.7 meters deep; pumps 151 liters per minute.	do	395.0	366.6
231	86881	do	Rizal, Camp Hyson	Well 2; 145.9 meters deep; pumps 76 liters per minute.	do	452.2	
232	88593	June, 1911	Rizal, Taytay	Well 272; 155.4 meters deep; pumps 227 liters per minute.	do	659.6	649.8
233	88594	do	Rizal, Alabang	Well 283; 173.7 meters deep; pumps 691 liters per minute.	do	438.2	426.0
234	93776	December, 1911	Rizal, Antipolo	Well 323 (Rizal 2); 68.3 meters deep; pumps 189 liters per minute.	do	196.0	174.7
235	Sample I	October, 1911	Rizal, Pasay	From open well on left side of cockpit.	do	890.5	825.0

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Date.	Locality.	Description.	Reaction.	Total solids.	Fixid solids.
236	Sample II	October, 1911	Rizal, Pasay	From open well at Calle Burgos, in front of municipal school and near the artesian well.	Alkaline	1,192.7	1,120.5
237	Sample III	do	do	Ordinary open well at No. 3 Calle Dominga, Pasay, half-way between the two previous wells.	do	787.7	725.2
238		do	do	Open well (1)	do	890.5	825.0
239		do	do	Open well (2)	do	1,192.7	1,120.5
240		do	do	Open well (3)	do	787.7	725.2
241	94089	November, 1911	Rizal, Alabang		Slightly alkaline	439.5	394.1
242	94640	January, 1912	Rizal, Taytay	Well 340	do	729.3	629.3
243	96857	February, 1912	Rizal, Antipolo	Well 302	Neutral	465.5	306.2
244	97143	do	do	Well	do	232.3	196.2
245	97863	do	Rizal, Taytay	Well 352	Alkaline	336.6	1.2
246	97864	do	Rizal, Tanay	Well 355	do	341.8	333.6
247	97869	do	do	Well 362	do	367.4	
248	98157	March, 1912	Rizal, Taytay	Well 344	do	606.8	582.4
249	98991	April, 1912	Rizal, Pateros	Well 380	do	2,422.6	2,322.8
250	99331	do	Rizal, Las Piñas	Well 386	do	606.4	603.4
251	101739	May, 1912	Rizal, Tagig	Well 388	do	1,107.2	1,102.2
252	101922	do	Rizal, Las Piñas	Well 392	do	614.6	
253	104044	June, 1912	Rizal, Tagig	Well 394	do	18,073.2	1,063.0
254	104529	July, 1912	Rizal, Parañaque	Well 404	do	626.6	612.6
255	104599	June, 1912	do	Well 417	do	358.0	330.2
256	105142	July, 1912	do	Well 412	do	875.2	865.4
257	105271	do	Rizal, Montalban	Well 423	do	164.2	157.8
258	105638	do	Rizal, Parañaque	Well 424	do	772.6	755.6
259	106255	August, 1912	Rizal, Pasay	Well 429	do	413.4	390.6
260	107040	September, 1912	Rizal, Pasay, San Roque	Well 438	do	1,502.6	

261	94869	January, 1912	Samar, Catbalogan	Well 311	Slightly alkaline	424.0	400.8
262	105977	August, 1912	Samar, Wright	Well 393	Alkaline	993.8	982.0
263	107944	October, 1912	Sorsogon, Sorsogon	Well 437	do	242.8	211.8
264	110866	December, 1912	do	Well 456	do	419.2	386.8
265	107344	September, 1912	Tarlac, Camiling	Well 419	Neutral	340.4	320.6
266	108992	November, 1912	do	do	Alkaline	268.6	
267	110789	December, 1912	do	Well 451	do	293.6	276.8
268	80287	July, 1910	Tayabas, Lucena	Well 178; 104.5 meters deep; flows 38 liters per minute.	do	951.2	
269	80450	August, 1910	Tayabas, Marinduque	Municipal well; 48.7 meters deep; flows 4 and pumps 19 liters per minute.	do	401.2	399.4
270	81495	do	Tayabas, Lucena	Well 178; 163.9 meters deep; flows 113.5 liters per minute.	Slightly alkaline	1,045.6	1,042.8
271	83798	October, 1910	do	do	Alkaline	992.6	973.6
272	84983	January, 1911	do	Well 212; 205.4 meters deep; flows 76 liters per minute.	do	1,816.0	1,804.2
273	85646	do	Tayabas, Marinduque	Well 1, Boac; 51.8 meters deep; pumps 60.5 liters per minute.		355.0	352.6
274	87523	April, 1911	do	Well 2, Boac; 51.8 meters deep; pumps 60.5 liters per minute.	Alkaline	399.8	
275	87526	do	do	Well 3, Boac; 47.2 meters deep; flows 9 and pumps 38 liters per minute.	do	525.2	523.8
276	96819	February, 1912	Tayabas, Pagbilao	Well 316	do	993.5	847.8
277	105742	August, 1912	Tayabas, Atimonan	Well 359	do	489.8	473.0

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters*[a]—Continued.

[L=little; N=nil; T=trace; U=undetermined.]

(Numbers give parts per million.)

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
1	54908	18.4	151.2	119.6	[c]29.6	[c]2.4	[c]35.8	[c]9.8	1.3			
2	83789	55.5	557.8	1,006.8	[c]87.4	[c]16.0	[c]354.9	100.8	78.0			Turbid. Blackens somewhat.
3	61024	94.8	65.8	297.6	[c]85.2	[c]0.8	[c]54.4	[c]85.24	T	N	347.0	Yellowish with little sediment. Blackens somewhat.
4	86551	45.6	958.8	332.4	56.2	3.0	101.4	96.1	4.1			Manganese tetroxide (Mn_3O_4) 5.2 parts per million.
5	107343	16.2	70.6	197.6	78.0	4.4	53.2	11.2	80.6			Slight coloration and smell of burnt earth.
6	78712	5.6	112.8	276.8	[c]93.2	[c]2.8	[c]74.8	[c]25.66		N	227.0	Physical character good.
7	79221	28.8	93.2	256.4	[c]80.8	[c]3.6	[c]55.6	[c]25.22		N	186.8	Do.
8	82704	11.0	59.2	173.0	[c]102.4	[c]2.8	[c]26.2	[c]9.7	[c]L	15.5	68.6	
9	84437	27.2	426.4	237.8	77.8	1.8	67.0	22.9	70.7			Slightly brown.
10	84438	23.6	468.6	226.2	73.2	1.8	58.4	22.8	76.2			Do.
11	84439	27.2	538.2	209.4	73.8	1.6	53.8	21.9	90.0			Do.
12	84440	13.2	543.6	136.8	59.2	1.6	21.6	12.9	78.4			Do.
13	84441	30.4	1,272.8	159.8	7.8	1.4	68.4	80.9	151.7			Do.
14	67333	16.0	134.5	230.2	[c]71.2	[c]0.9	[c]54.5	[c]29.93	3.8	N	167.6	Brownish.
15	2488	232.0			31.5	4.2	74.74	82.36	159.41			
16	93292	0.8	481.2	158.2	121.8	4.6	6.6	3.6	56.7			Yellowish.
17	95430	74.9	382.1	189.7	78.5	6.5	32.2	33.6	15.8	17.0	129.2	Brownish white.
18	98447	1.8	1,164.8	109.6	63.2	3.2	20.4	7.8	34.7			Slight browning.
19	105125	22.0	55.2	218.2	94.0	3.0	48.6	16.8	12.6			Little blackening.
20	109934	7.0	84.0	185.0	83.6	3.8	34.8	11.2	26.8			
21	108462	9.2	114.0	202.0	72.0	6.0	50.0	12.6	47.4			Blackening.
22	1006a						71.1	7.14				Clear and tasteless.

23	1006b					T	180.0	3.2				Hydrogen sulphide 12.1 cc. per liter. Sulphur taste and odor.
24	1006c						71.9	4.9				Hydrogen sulphide 2.07 cc. per liter. Clear and tasteless.
25	1006d						87.0	5.5				Hydrogen sulphide 4.67 cc. per liter. Clear and tasteless.
26	1006e						109.0	20.9				Mineral (lime) deposit; clear, odorless. Volume hydrogen sulphide, 0.96 cc. per liter.
27	1006f						85.7	11.9				Thick yellowish sediment (lime?). Volume hydrogen sulphide, 7.32 cc. per liter.
28	1006g						197.0	4.3				Volume hydrogen sulphide, 0.65 cc. per liter. Sulphur taste and odor.
29	1006h						141.4	17.3				Blue and green deposit.
30	1006i						101.0	3.6				Volume hydrogen sulphide, 17.4 cc. per liter. Dark brown deposits.
31	1006j						145.2	10.7				Clear, tasteless. Yellowish (lime?) deposit.
32	1006k						T	N				Volume hydrogen sulphide, 1.00 cc. per liter.
33	1006l						10.0	T				Tasteless and odorless.
34	1006m						T	T				Tasteless and clear.
35	90142	14.6	558.2	303.8	43.2	1.4	252.4	52.9	397.7			
36		7.0	122.2	182.6	41.4	1.0	68.6	24.2	13.8			
37	99591				14.8	7.8	4.2	1.8	54.1			Blackening and evolution of SO_2. One liter required 1.2 cc. N/10 NaOH to neutralize.[d]
38	99591				16.6	2.2	3.6	2.8	46.8			One liter of sample required 7.7 cc. N/10 NaOH to neutralize.[e]
39	80289	82.4	1,665.6	398.8	55.8	0.4	144.4	144.9	148.5	248.2	78.2	Evolution of hydrochloric acid.

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
40	83330	14.8	105.65	343.55	23.2	2.6	191.95	T	240.10			Turbid, brownish sediment.
41	83331	50.8	104.55	409.85	16.65	2.05	239.35	T	231.3			Slight browning. Turbid.
42	83717	216.5	1,825.0	506.3	43.1	1.2	179.1	150.7	397.0			
43	83743	57.0	945.8	455.4	12.7	0.5	232.4	200.7	245.8			Slightly brown.
44	91226	51.4	1,135.8	416.4	22.8	T	179.6	110.4	95.46			
45	93928	25.7	25.9	294.4	13.5	0.4	60.1	36.5	6.0	N	314.0	Source of supply of proposed water system for Loay.
46	93941	41.0	322.6	63.2	1.2	11.7	164.3	3.3	24.0	N	97.0	White. The demijohn had a strong smell of wine.
47	94257	23.6	68.8	238.6	11.2	T	154.5	2.1	12.5	90.2	265.5	White.
48	96694	125.5	361.5	215.3	11.3	15.0	149.0	24.0	20.8	109.5	151.3	Do.
49	97168	17.2	58.0	190.2	40.3	T	83.2	8.4	7.6	U	U	White. Total hardness 166.6.
50	97865	L	28.2	221.6	20.4	1.2	107.2	18.5	8.3			
51	104914	7.0	51.4	262.6								
52	46442	6.9	356.0	35.0	20.7	0.5	5.4	0.9	T			Blackening.
53	47956	2.4	364.7	35.6	c20.9	c0.6	c6.6	c0.68	c1.03			
54	47957	11.3	457.4	142.2	c40.5	c0.6	c32.5	c23.0	c2.5			
55	49775	17.1	231.8	28.2							71	Slight blackening.
56	52562	24.0	221.1	35.7	26.8	1.6	2.3	T	N		8.5	Do.
57	53508	10.2	205.6	38.5								Slight blackening. Same source as No. 52562.
58	54721	0.6	196.2	23.6	c17.2	c1.1	c1.6	cT	c0.3			
59	56949	0.4	181.2	49.6								Blackening.
60	56965	17.4	185.8	27.8								
61	57479	22.4										Same as No. 56965.
62	58273	20.4	187.6	39.6	c28.4	c1.6	c2.8	c0.15	cT			Blackening.
63	78825	2.4	220.8	120.2	c92.6	c1.2	c8.2	c1.96		N	31.3	

64	85759	18.2			84.8	2.0	33.8	1.68	5.56			
65	87524	6.2	1,004.4	84.8	26.6	1.0	37.0	2.03	7.88			Salty taste. Clear and transparent.
66	89432	L	971.0	78.2	23.2	0.2	42.6	L	L			Slight browning.
67	42794	33.2	747.2	190.2	c34.1	c0.5	c63.0	c41.2	c8.0	119	37	Very slight blackening.
68	43533	16.2	549.2	134.8	c79.8	c0.8	c13.9	c7.9	c1.23			Slight browning.
69	44052	31.2	1,126.2	234.4	c87.4	cT	c55.2	c23.9	c1.8			
70	97049	32.5	1,023.0	58.8	21.5		44.5	2.1	5.10	47.9	25.5	Clear, colorless, odorless.
71	97173	17.1	70.4	213.7	21.0	2.0	135.6	3.2	0.82	46.5	187.1	White.
72	97174	22.3	94.5	296.4	19.7	2.3	168.6	20.07	13.30	48.3	194.8	White. Clear, colorless, odorless.
73	98529	5.4	811.0	80.0	18.2	2.0	41.2	1.8	9.8			
74	102056		260.0	20.0	18.0	0.6	4.2	1.0	17.2			Slight blackening.
75	105141	20.6	1,263.8	55.2	24.0	0.4	59.0	4.9	1.6			
76	109843	10.4	733.4	77.8	18.0	1.2	37.0	1.3	T			Blackening.
77	79649	1.6	2,632.8	239.0	17.0	0.6	418.6	1.45	210.48	758.4	T	
78	87656	28.4	1,346.6	347.8	22.4	1.4	131.8	104.4	109.4			Browning and evolution of hydrochloric acid.
79	58645	32.0	552.8	283.6	c64.0	c0.8	c98.8	21.2	c4.38	55.6	218.0	Turbid. Clear on filtration.
80	58765	26.4	486.8	283.2	c71.6	c0.8	c94.0	19.3	c4.38	48.0	200.5	
81	74811	10.2	364.4	123.2	c87.6	c1.6	c6.4			N	32.0	Brownish color.
82	75304	19.6	89.6	244.4	c106.2	c3.8	c52.6	c15.07	cL		146.0	
83	77565	12.8	117.2	224.8	c98.8	c6.4	c42.2	c15.1	cT	N	133.5	
84	78903	2.4	398.2	111.8	c71.4	c0.4	c13.4	c3.5		N	43.05	Physical character good.
85	80288		173.2	207.6	84.2	2.2	51.6	22.83	32.58	11.46	144.44	
86	80790	L	412.8	101.8	85.8	1.6	5.4	0.43	43.6	2.9	7.59	Do.
87	83352	15.8	120.7	260.3	c88.6	c1.9	c55.1	cT	c58.7			Brownish. Turbid.
88	83950	20.8	139.8	248.4	c73.8	c1.6	c52.0	c20.0	c8.8			Brownish. Physical character good.
89	83799	1.4	413.8	85.6	80.6	T	1.5	1.6	18.8			White. Physical character poor.
90	88873	13.8	151.6	230.8	80.8	2.8	55.4	22.2	24.07			Some blackening. Brownish color.
91	88878	12.6	145.8	232.2	78.6	1.4	50.6	20.95	22.29			Some blackening. Brown color.
92	89998	8.4	94.6	294.6	93.4	4.2		22.04	12.68			Slight blackening.
93	107605	28.2	230.2	157.4	87.6	4.8	18.6	7.1	24.3			Browning.

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
94	109674	16.4	179.6	214.0	81.2	2.4	44.4	17.8	24.8	----------	----------	
95	110193	10.4	129.2	227.8	87.6	2.0	44.2	20.4	10.2	----------	----------	
96	71504	8.4	191.6	c 254.4	c 44.4	c 0.8	c 74.8	c 23.77	L	N	222.0	Physical character excellent.
97	71504	1.6	471.2	131.6	c 39.2	c 0.6	c 27.4	c 20.15	L	N	106.0	
98	91643	L	130.2	208.0	27.6	4.0	52.8	68.2	24.3	----------	----------	
99	20914	25.5	1,398.50	75.00	c 41.75	c 1.50	11.25	c 12.61	92.34	----------	----------	
100	28301	52.0	1,481.00	96.00	c 37.00	c 2.00	13.00	c 19.47	4.12	----------	----------	Volume hydrogen sulphide, 2.20 per million.
101	29455	68.0	2,381.40	134.40	c 27.00	c 10.80	c 53.80	29.20	2.74	----------	----------	Colorless, transparent, little sediment, and no odor.
102	31293	149.0	4,155.00	239.5	c 30.2	c 0.9	c 92.2	c 54.7	T	----------	----------	Colorless and transparent.[f]
103	36976	82.3	268.6	494.40	c 36.00	c 1.70	214.80	c 36.24	c 41.15	----------	----------	
104	39089	4.2	71.7	315.7	c 46.4	c 0.4	c 133.0	c 23.49	c 3.09	3.8	25.35	
105	95541	14.2	96.0	289.2	24.8	0.8	130.0	18.8	2.5	25.0	27.0	
106	94003	49.8	32.0	136.0	46.7	T	55.5	13.9	T	N	179.6	
107	94003	49.0	47.2	112.8	33.7	T	59.1	16.9	T	N	196.0	
108	94003	53.7	42.0	80.0	26.4	T	60.1	9.3	T	N	202.0	
109	94003	72.3	51.1	118.1	41.2	T	50.0	26.9	T	N	201.9	
110	96990	49.5	88.8	237.7	30.4	1.8	92.6	5.3	5.4	U	U	Total hardness, 154.4
111	97268	8.2	41.8	268.2	42.6	1.8	147.2	1.8	10.3	----------	----------	Slight browning.
112	99397	0.4	385.0	135.8	28.4	3.0	46.2	33.6	52.6	----------	----------	Slight blackening. Turbid with clayish sediment.
113	58254	82.8	367.6	258.8	71.2	2.8	70.8	40.3	T	N	23.8	Blackening.
114	88400	942.4	2,287.4	922.0	81.6	1.8	825.0	382.08	188.48	----------	----------	Excessive blackening and evolution of much hydrochloric acid.
115	88400	17.0	38.4	239.8	72.2	2.4	59.8	39.43	5.35	----------	----------	Slight brownish color.

116	90607	2.2	313.6	422.0	6.4	0.6	173.4	80.98	70.1	-----	-----	
117	98446	1.0	38.2	177.8	45.6	1.0	61.8	11.8	9.2	-----	-----	
118	110499	10.6	1,329.0	20.0	12.0	0.8	6.8	2.3	12.5	-----	-----	Blackening.
119	59352	18.0	392.2	495.6	c28.0	c0.4	221.6	c33.6	8.6	81.0	464.0	
120	59353	10.8	123.6	185.6	c24.8	c0.4	70.4	c19.3	-----	-----	174.0	
121	68657	8.8	112.4	183.2	c22.8	c0.8	73.6	c14.5	c3.29	1.05	188.30	
122	68658	28.8	300.4	312.0	c91.6	c3.2	88.0	c31.02	10.97	95.2	219.0	
123	68659	8.4	155.6	153.6	c21.6	c1.2	c60.4	c13.92	c2.33	N	155.5	
124	68660	88.8	326.4	641.2	c29.6	c1.6	c278.8	c51.9	c79.8	215.5	498.4	Much blackening on ignition.
125	74899	26.8	2,720.4	151.6	c53.2	c4.0	17.2	c24.1	N	N	182.0	Little blackening. Brownish yellow color with odor.
126	75306	10.4	1,136.8	55.2	c20.8	3.2	10.8	c5.22	N	N	60.2	Light brown.
127	85947	-----	-----	-----	77.2	27.2	160.0	1.08	54.94	-----	-----	Browning, slightly turbid, and little earthy sediment.
128	15676(3442)	18.1	382.0	44.1	30.2	1.8	12.0	0.86	10.16	23.4	19.5	
129	15676(3443)	172.8	175.2	119.2	16.0	6.4	176.0	28.11	T	65.2	214.4	
130	15676(3444)	180.0	188.0	104.0	9.6	12.0	180.0	10.14	49.3	52.3	203.3	
131	32180	40.8	1,499.3	217.1	c55.0	c0.4	c65.1	c1.20	89.66	-----	-----	
132	35024	141.5	157.8	248.8	c55.6	c4.0	c65.2	c28.19	c38.06	-----	-----	
133	35025	118.5	178.8	-----	c30.0	c4.0	c62.0	c26.50	c22.46	-----	-----	
134	94862	247.3	7,751.2	199.0	25.5	10.0	63.0	61.24	1.71	15.4	471.3	Brownish white. Dark brown.
135	107186	33.0	1,607.2	518.2	67.0	1.6	169.0	50.3	5.5	-----	-----	Blackening and slight odor of vegetable matter.
136	108062	30.0	1,620.0	594.8	64.8	T	166.0	92.7	4.4	-----	-----	Blackening.
137	109063	182.5	1,758.0	805.5	44.5	9.0	326.5	160.0	12.3	-----	-----	Do.
138	110053	38.0	1,640.0	475.2	72.4	4.0	140.8	80.4	14.9	-----	-----	
139	79009	11.2	14.2	83.8	c40.8	c1.2	c12.4	c8.77	-----	N	50.85	
140	58171	6.0	54.8	155.8	82.0	3.0	19.6	15.00	-----	-----	71.00	
141	58240	30.4	-----	-----	-----	-----	-----	-----	-----	-----	-----	
142	58483	27.4	46.0	159.2	c76.0	c2.4	c20.8	c15.60	-----	-----	80.00	
143	58575	74.4	244.0	183.6	c72.4	c4.0	c29.6	c26.89	L	-----	161.60	Blackening and organic odor. Brownish yellow and turbid, but clear on filtration.

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
144	92745	9.4	128.4	261.2	93.4	L	69.8	16.6	13.3	....	....	Physical character normal.
145	93063	36.8	....	....	60.8	1.2	139.6	51.4	59.3	....	....	Little blackening. Physical character normal.
146	93063	23.8	....	....	76.2	0.2	177.0	39.9	45.6	....	....	Physical character normal.
147	93063	33.4	....	....	71.2	0.4	53.4	21.16	14.6	....	....	Do.
148	93063	40.8	....	....	73.2	1.0	157.0	54.6	58.2	....	....	Slight evolution of oxide of nitrogen. Physical character normal.
149	93552	78.1	138.4	176.0	97.2	0.1	50.0	24.9	9.6	N	282.6	
150	98927	90.6	106.8	184.5	92.6	T	46.7	28.70	4.20	N	362.00	
151	107603	26.0	241.2	255.4	105.6	4.4	38.6	8.4	7.5	....	....	Slight blackening.
152	108464	27.8	64.2	211.8	90.2	T	38.0	23.8	10.5	....	....	
153	108464	N	79.0	222.6	96.0	T	44.0	27.3	8.5	....	....	
154	108464	21.8	47.0	222.2	93.2	T	40.0	27.8	4.9	....	....	
155	110480	20.0	218.4	215.6	68.4	1.6	40.2	8.5	T	....	....	
156	94767	69.3	122.2	202.5	100.5	T	62.0	24.5	14.2	45.8	269.9	White. Clear, colorless.
157	94992	49.1	502.8	203.2	87.2	2.2	52.5	30.4	4.64	17.4	254.2	Clear, colorless, odorless.
158	94993	50.2	105.8	194.2	91.7	0.8	0.4	31.49	5.24	N	256.6	White. Clear, colorless, odorless.
159	97081	34.7	33.4	141.4	35.3	1.3	85.1	8.5	18.7	U	U	White. Total hardness, 101.3.
160	97537	L	136.8	231.0	82.8	2.2	54.6	32.18	12.27	....	....	
161	68605	67.0	....	....	c 113.6	c 4.0	c 330.0	c 148.6	c 13.0[3]	....	....	Darkening. Reddish sediment of carbonates.
162	68197	32.8	....	....	108.8	c 2.0	383.5	c 102.93	c 8.70	N	950.50	Somewhat greenish and turbid.
163	55928	19.2	776.8	89.2	48.0	0.8	20.9	T	7.7	....	....	
164	55928	14.4	774.8	88.4	48.8	0.4	19.6	T	7.8	....	....	
165	55928	15.6	774.0	87.6	46.8	0.4	20.5	T	8.2	....	....	

166	55928	13.6	772.8	88.4	46.4	0.4	19.4	T	7.5			
167	58797	S	187.6	30.8	c 21.6	0.4	2.4	T	T	N	3.30	
168	21071	29.4	272.0	101.0	56.0	3.0	13.0	5.00	21.30			
169	26951	74.0										
170	38446	31.1	236.9	159.5	c 51.8	c 1.0	c 12.9	c 49.3	0.3			
171	46104	311.6	1,048.0	570.7	66.0	11.8	301.2	8.0	28.8			
172	52172	869.0	6,512.8	842.2	56.8	47.6	166.4	229.6	63.2			Evolution of hydrochloric acid. Salty taste.
173	54050	77.2	1,471.6	247.2	c 34.8	c 1.6	79.2	c 38.3	23.20			Do.
174	15898	116.0			129.6	T	43.3	23.0				Very turbid; contains carbonates of iron and suspended matter.
175	98259	6.6	346.2	149.8	76.6	1.0	19.0	9.3	32.9			It will precipitate a hard scale due to silicates and sulphates. Little blackening.
176					62.0	9.0	9.0	5.2	19.2			Blackening.
177	77822	8.8	31.2	106.4	c 25.8	c 0.8	c 34.8	c 8.63	c T	16.6	90.0	Little blackening.
178	110865	66.8	1,179.6	199.6	56.8	3.6	31.2	64.4	6.8			Slight blackening.
179	79220	31.6	156.4	385.4	c 54.6	c 3.2	c 139.6	34.94	c 34.56	158.4	276.9	Slightly brown.
180	82585	23.8	51.2	249.4	60.2	1.8	81.6	25.8	3.7	12.6	187.9	Physical character good.
181	94613	12.5	204.3	23.2	23.0	T	4.3	0.79	16.00	N	161.5	Colorless, odorless.
182	48209	2.6	321.4	115.6	c 91.2	c 0.4	c 4.0	c 1.73	c 2.4			
183	48210	4.6	312.6	105.4	c 78.4	c 0.6	c 4.8	c 2.38	c 2.2			
184	48214	4.6	326.8	102.2	c 81.0	c 1.4	c 2.6	c 1.73	c 2.3			
185	48263	2.6	256.2	100.2	c 38.6	c 1.0	c 23.2	c 5.6	c 1.23			
186	48268	19.8	1,000.2	187.0	c 84.8	c 2.8	c 15.2	20.68	T			Browning and organic odor.
187	48269	10.8	185.6	118.4	c 84.6	c 0.8	c 3.6	c 3.09	c 1.58			
188	48270	5.2	326.0	115.6	88.2	c 0.6	c 5.0	c 1.5	N			
189	48311	0.8	162.2	80.8	c 38.4	c 1.0	c 14.2	c 2.16	c 1.16			
190	48312	1.4	154.2	78.6	c 29.6	c 1.8	c 18.4	c 2.31	c 0.55			
191	108533	2.0	302.0	114.0	75.0	1.6	6.8	0.3	16.0			Fair for boiler use.
192	106711		290.0	112.4	94.2	1.6	4.8	T	234.9			

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
193	88271	2.4	86.4	121.0	31.0	2.2	52.2	8.3	51.4	----------	----------	Slight blackening. Slightly brownish and turbid with clayey sediment.
194	60753	22.2	409.8	71.0	c 42.8	c 0.8	c 8.4	c 1.23	T	----------	23.4	Little browning.
195	67008	26.0	512.6	74.4	c 17.6	c 3.2	c 23.8	c 3.2	L	----------	52.18	Slight browning. Physical character good.
196	68617	3.6	231.2	118.8	c 78.8	c 0.4	c 14.8	c 2.32	T	N	42.35	Slight darkening. Physical character good.
197	80060	L	171.2	92.02	c 72.4	c 0.8	c 5.8	T	c 18.93	10.06	9.43	
198	85906	16.6	----------	----------	48.6	c 4.6	c 68.4	c 9.57	c 10.56	----------	----------	Little browning. Brownish color with earthy sediment.
199	86306	L	255.2	55.6	33.0	1.4	14.4	6.48	26.06	----------	----------	Little sandy sediment.
200	91192	31.4	432.2	326.8	63.6	1.8	130.2	41.02	52.94	----------	----------	
201	64559	8.6	673.2	99.4	c 23.2	c 2.6	c 41.0	c 4.2	c 7.2	----------	----------	Blackening. Brown color.
202	67973	10.5	194.9	65.6	c 26.0	c 0.2	c 15.6	c 1.1	c 23.73	101.0	3.56	Blackening. Turbid with white flaky sediment.
203	93693	44.6	673.4	44.0	38.0	1.8	17.0	10.6	18.4	N	400.0	
204	92450	----------	----------	----------	40.2	2.4	78.6	7.9	27.2	----------	----------	
205	94707	57.3	672.1	74.2	47.8	8.7	25.2	9.4	12.5	N	497.6	Brown.
206	105444	3.0	117.6	148.0	32.8	4.4	62.6	7.0	31.7	----------	----------	
207	106337	1.6	167.8	57.4	39.8	0.6	7.0	----------	----------	----------	----------	
208	108254	16.4	77.6	181.6	63.0	1.0	47.0	----------	----------	----------	----------	Evolution of hydrochloric acid.
209	106814	----------	474.0	330.4	69.6	1.6	148.2	19.3	5.7	----------	----------	
210	57372	19.1	194.3	168.3	60.5	1.1	30.8	12.9	7.2	----------	----------	
211	58444	77.2	206.4	293.2	c 100.8	c 4.8	c 83.2	c 25.2	c T	----------	310.8	Blackening. Smells of sulphureted hydrogen. Slightly turbid and brown.

212	59533	29.2	238.4	179.2	70.4	c 1.6	40.0	c 13.7	c L		110.9	Physical character good.
213	59580	410.4	255.6	174.4	c 81.6	c 2.8	c 36.8	c 8.5	c L		102.5	Do.
214	58796	L	233.2	34.8	c 21.6	c 0.4	c 2.8	c T	c T	N	4.0	
215	61809	20.40	195.2	172.6	c 71.4	c 1.2	c 36.2	c 13.25	c T		101.75	Do.
216	65576	2.5	205.3	65.8	c 46.8	c 0.2	c 4.2	c 4.6	L		21.3	Blackening. Brownish.
217	67694						c 246.4	113.1		446.0	234.1	Evolution of hydrochloric acid. Brackish taste.
218	67895	20.0	201.0	161.1	c 64.7	c 2.4	c 32.6	c 12.1	T		88.29	Blackening.
219	68170	14.8	76.6	151.1	c 34.8	c 0.8	c 49.8	c 12.8	T	N	111.0	Slight brown color.
220	68454	8.0	558.4	112.4	c 62.4							Slight darkening.
221	68815	24.0	2,089.2	270.0	c 67.6	c 1.2	c 86.4	c 7.4	c 85.2	133.45	97.6	Slight browning. Turbid with salty taste.
222	70116	6.4	251.2	178.0	c 74.4	c 0.8	c 38.4	c 13.26	L		96.0	Physical character excellent.
223	71619	L	274.4	46.0	c 35.2	c 0.4	c 3.4	T	N	N	12.0	
224	72086	17.6	857.2	147.6	73.6	1.6	27.8	c 4.42	N	N	73.8	
225	72529	36.8	1,212.4	206.4	c 66.8	0.8	c 55.6	27.4	U	76.4	160.1	
226	80095	7.2	3,352.4	110.6	c 60.2	0.8	414.8	25.08	103.22	800.04	10.8	Greenish sediment.
227	80594	10.4	892.0	169.2	49.4	3.6	66.4	62.2	34.5			With greenish mossy sediment.
228	86832	4.2	208.6	65.8	56.6	1.2	2.8	0.6	44.72			
229	87525	0.4	180.2	225.8	93.8	1.8	47.8	15.6	13.5			Brown color.
230	86881	28.4	143.0	223.6	81.8	0.8	46.6	8.48	12.75			
231	86881	L	126.6	326.6	111.4	0.6	91.0	36.606	11.04			
232	88593	9.8	372.2	277.2	72.8	7.2	90.4	38.5	207.8			Turbid with clayey sediment.
233	88594	12.2	243.0	183.0	79.2	3.6	37.2	9.5	17.5			
234	93776	21.3	14.4	160.3	117.5	T	23.0	5.87	3.2	N	92.0	
235	Sample I	65.5			54.0	T	223.0	73.2	72.5			Slight browning. Physical character normal.
236	Sample II	72.2			43.7	T	217.0	90.5	123.2			Blackening; slight smell of burning organic matter. Brown color.
237	Sample III	62.5			19.7	T	191.1	58.7	57.7			Slight browning. Brownish color.
238		65.5			54.0	T	223.0	73.2	72.5			Slight browning. A hard water.
239		72.2			43.7	T	217.0	90.5	123.2			Do.

NOTE.—Footnotes follow at the end of the table, p. 371.

TABLE VII.—*Technical analyses of Philippine waters* [a]—Continued.

Tracing No.	Laboratory No.	Loss on ignition.[b]	Nonscale-forming ingredients.	Scale-forming ingredients.	Silica (SiO_2).	Alumina (Al_2O_3) and ferric oxide (Fe_2O_3).	Lime (CaO).	Magnesia (MgO).	Sulphuric anhydride (SO_3).	Permanent hardness.	Temporary hardness.	Behavior of residue on ignition, and remarks.
240	----------	62.5	----------	----------	19.7	T	191.1	58.7	57.7	----------	----------	Slight browning. A hard water.
241	94089	45.4	249.8	144.3	91.2	T	39.5	10.8	2.0	N	289.5	
242	94640	100.0	375.7	303.0	95.8	T	129.5	29.8	10.2	58.5	190.3	Do.
243	96857	159.3	99.0	207.2	81.0	6.4	79.7	29.9	14.2	----------	T	Brownish white.
244	97143	36.1	18.8	177.4	47.4	T	97.1	T	20.8	----------	----------	
245	97863	15.4	79.4	242.8	49.8	4.4	75.2	34.7	8.78	----------	----------	
246	97864	8.2	53.0	280.6	86.6	4.8	72.8	31.46	9.1	----------	----------	
247	97869	L	87.2	280.2	79.2	4.0	90.6	23.0	8.7	----------	----------	
248	98157	24.4	316.6	265.8	63.0	2.4	85.6	29.3	143.7	----------	----------	
249	98991	99.8	1,828.0	494.8	61.0	5.8	217.2	117.7	L	----------	----------	Blackening and evolution of hydrochloric acid.
250	99331	3.0	477.4	126.0	90.8	0.4	15.8	1.9	23.9	----------	----------	
251	101739	5.0	937.2	165.0	91.2	12.4	25.6	L	105.56	----------	----------	
252	101922	----------	489.4	125.2	89.6	0.8	17.0	1.9	26.1	----------	----------	
253	104044	10.2	88.6	174.4	82.0	1.8	43.2	9.3	128.8	----------	----------	
254	104529	14.0	488.8	123.8	83.8	1.8	4.4	1.5	18.9	----------	----------	
255	104599	27.8	139.8	190.4	----------	----------	----------	----------	----------	----------	----------	
256	105142	10.8	735.2	130.2	78.8	3.8	9.4	4.3	39.7	----------	----------	Little blackening. Turbid with red earthy sediment.
257	105271	6.4	33.8	124.0	35.6	1.8	43.8	9.5	9.8	----------	----------	Little blackening.
258	105638	17.0	623.8	131.8	80.8	1.8	9.8	2.1	62.2	----------	----------	
259	106255	22.8	159.4	231.2	92.2	2.2	44.2	19.3	5.7	----------	----------	
260	107040	----------	1,145.6	357.0	90.8	4.6	147.8	60.0	24.7	----------	----------	Evolution of hydrochloric acid.
261	94869	23.2	371.8	29.0	37.9	0.2	2.1	T	28.3	N	243.4	Blackening and smell of burnt organic matter.
262	105977	11.8	948.2	33.8	----------	----------	----------	----------	----------	----------	----------	
263	107944	31.0	30.0	181.8	87.6	4.6	26.4	16.8	65.9	----------	----------	Browning.

264	110866	32.4	90.4	296.4	88.8	2.8	75.6	44.4	5.8	----------	----------	
265	107344	19.8	181.4	139.2	14.6	3.4	40.8	35.8	3.6	----------	----------	Blackening and acrid smell.
266	108992	N	143.6	125.0	27.0	0.4	31.8	23.1	L	----------	----------	Has improved since last analysis.
267	110789	16.8	38.4	238.4	42.8	2.0	59.2	68.3	9.3	----------	----------	If previously freed from temporary hardness, suited for technical use.
268	80287	6.8	911.0	40.2	25.2	1.4	5.8	1.74	119.06	6.27	7.42	Brownish yellow with little earthy sediment.
269	80450	1.8	155.6	243.8	65.8	2.8	36.4	15.2	188.5	28.8	171.20	
270	81495	2.8	957.8	85.0	65.8	1.2	4.2	T	103.08	231.0	4.62	Blackening. Brown color.
271	83798	19.0	889.0	84.6	63.0	T	1.3	0.6	92.2	----------	----------	Brown color.
272	84983	11.8	1,681.2	123.0	58.8	1.8	22.4	6.23	213.16	----------	----------	Slight blackening.
273	85646	2.4	229.6	123.0	27.0	0.2	28.8	30.88	25.44	----------	----------	Slight browning.
274	87523	L	257.4	142.4	37.4	1.8	33.6	31.5	26.1	----------	----------	Brown color.
275	87526	1.4	439.8	84.0	29.4	3.4	10.2	8.8	10.4	----------	----------	Slight browning. Brownish yellow color.
276	96891	145.7	487.4	360.0	90.5	3.6	134.4	84.6	28.7	136.3	72.9	
277	105742	16.8	216.2	256.8	45.6	1.6	98.6	28.9	56.4	----------	----------	

[a] To convert parts per million into grains per U. S. gallon, multiply by 0.05835 or divide by 17.124.

[b] After recarbonation.

[c] In scale-forming ingredients.

[d] Cannot be recommended for boiler feed water unless previously treated.

[e] Cannot be recommended for boiler feed water unless previously neutralized. The "total solids" is less than the sum of the ingredients, on account of the volatilization of sulphuric acid on drying the total solids at a temperature of about 200° C.

[f] Water in this well rises and falls with tide, although overflow remains 1.5 meters or more above the surrounding ocean.

[g] From Guadalupe Creek 4.8 kilometers west of town of Guadalupe and just below the confluence of its two branches.

The commonest purpose of technical analyses in the Philippines is the determination of the fitness of water for the production of steam, for the purity of the water to be evaporated is recognized as a very important factor. The manufacturing industries in the Philippines are generally in an undeveloped state, and few specific troubles have been encountered that can justly be ascribed to the water. Most of the establishments, particularly those at Manila, have had little or no trouble in obtaining an adequate supply of suitable water. Many of the industries, of which tanning is an example, are carried on in such primitive fashion that the question of the quality of water used seldom comes up for consideration, but this question will become more and more significant as manufacturing industries develop.

The chemical composition of a feed water plays an important part in the formation of scale and sediment, in the corrosion of metals, and in the causing of priming and foaming. Few natural waters are entirely suitable for boiler use without previous treatment. Even distilled water may have a corrosive action on boiler parts. Rain water, or a heavy fall of snow melting quickly on watersheds, is sure to give to its drainage rivers a water which has a highly corrosive action when used in boilers.[27]

CONSTITUENTS

The following classification shows the effect of different ingredients in boiler waters:

Calcium carbonate ($CaCO_3$) Magnesium carbonate ($MgCO_3$) Calcium sulphate ($CaSO_4$) Magnesium sulphate ($MgSO_4$) Silica (SiO_2) Iron oxide (Fe_2O_3) Aluminium oxide (Al_2O_3) Grease, suspended matter, mud	Cause scale formation.
Sodium chloride ($NaCl$) in the presence of calcium and magnesium salts Magnesium chloride ($MgCl_2$) (due to decomposition of this salt at high temperatures) Calcium chloride ($CaCl_2$) Potassium chloride (KCl)	Cause corrosion.
Alkali salts	Cause priming.

Calcium carbonate.—Calcium carbonate is almost insoluble in water. Water containing carbonic acid dissolves calcium carbonate more freely on account of the formation of the more soluble bicarbonate, and this is the

[27] Kent, Steam Boiler Economy. J. Wiley and Sons, New York (1901), 313.

form in which it usually exists in water. The carbonate may be precipitated by boiling, and it forms a soft mud in boilers unless sulphates are present when with the other sediments it is cemented together into a very hard and insoluble scale.

Magnesium carbonate.—Magnesium carbonate is slightly soluble in water, and therefore when held in solution by the presence of carbonic acid will not be entirely precipitated by boiling off the excess of carbon dioxide. Magnesite (natural magnesium carbonate) is used as a pipe covering to reduce radiation. It is, therefore, obvious that it should be avoided as scale.

Calcium sulphate.—Calcium sulphate is somewhat soluble in both pure and salt water and unlike most salts in inverse ratio to the temperature up to 150°C. This temperature corresponds to a steam pressure of 4.7 kilograms per square centimeter (67 pounds per square inch), and at this pressure all gypsum is deposited before any consequential evaporation has taken place. In boilers it becomes precipitated as fine crystals not so much by concentration as by the elevation of the temperature which when mixed with the mud in the boilers forms a hard undesirable scale so difficult to remove that it can be accomplished only by chipping. This scale may be recognized by its vitreous appearance.

Magnesium sulphate.—Magnesium sulphate alone does not form any scale in boilers. When present in water with calcium carbonate it reacts with the latter and forms a scale which is generally considered to be a combination of calcium sulphate and hydrated magnesium oxide, one of the hardest scales known.

Silica.—Silica is present in most natural waters as a colloid. It may be precipitated by boiling, and is occasionally found in considerable quantities in scale. The scale formed from it is not excessively hard, and has no very characteristic physical properties. When it is deposited with calcium sulphate, it forms a very hard scale which is difficult to remove.

Iron and aluminium.—These metals are found in most natural waters and may be considered as incrustants, appearing in the scale as oxides or hydrated oxides, although neither of them is particularly troublesome especially because they are generally present in feed water in very small amounts. Iron derived from corrosion of the boiler may be added to the scale. When too much aluminium sulphate is used as a coagulant for feed water, the excess of the salt may enter the boiler and cause trouble, since, by hydrolysis, sulphuric acid is formed which is highly corrosive.

Grease.—The action of grease, especially fatty substances, readily decomposed by heat in a boiler is to form a soft deposit similar to scale but with ten times greater resistance to heat which even more seriously interferes with the transmission of heat. Mud and sediment must be blown off else they will harden and produce dangerous scale.

SCALE FORMATION

Certain dissolved mineral matter remains in solution at low temperatures, but is precipitated when the water is heated or concentrated, and falls to the bottom or is deposited on the boiler tubes and shell.[28] With pure water the evaporation efficiency per unit of heating surface will not vary greatly

[28] When precipitation takes places inside the water or steam space it is called sediment, but if deposition forms a hard coating on the water-heating surface it is called scale.

for different boilers, but with waters containing varying amounts of scale-forming ingredients the efficiency of all boilers is seriously interfered with. The question as to whether a given water is satisfactory can be decided only when its chemical composition is known. Although it is difficult to fix an arbitrary standard, the following classification of waters with reference to their suitability for boiler use serves very well for practical work. The figures show the number of parts of scale-forming solids in a million parts of water.

Quality of water for boiler purposes.[a]

Less than 90 parts per million	Good.
90 to 200 parts per million	Fair.
200 to 430 parts per million	Poor.
430 to 680 parts per million	Bad.
Over 680 parts per million	Very bad.

[a] *Proc. Am. Ry. Eng. & Maintenance of Way Assoc.* (1904), 5, 595.

If the amount of scale-forming ingredients in water for boiler use is high, the interiors of the shell and tubes of the boilers become coated with scale which offers one hundred times the resistance of steel to heat and seriously interferes with the transmission of the latter. Steel is not a remarkably good conductor of heat when clean, and a very thin coating of scale often markedly shows in loss of heat.

The effect of scale on the transmission of heat through a boiler tube is extremely variable, the mechanical structure of the scale at least as important a factor as the mere thickness. A hard scale 7 or 8 millimeters thick may result in a reduction of from 15 to 20 per cent in the evaporation.[29] Schmidt and Snodgrass[30] have investigated the effect of scale on the transmission of heat in locomotive boiler tubes, and feel warranted in summing up the results of their tests in the following conclusions:

"1. Considering scale of ordinary thickness, say of thickness varying up to one-eighth inch, the loss in heat transmission due to scale may vary in individual cases from insignificant amounts to as much as 10 or 12 per cent.

2. The loss increases somewhat with the thickness of the scale.

3. The mechanical structure of the scale is of as much or more importance than the thickness in producing this loss.

4. Chemical composition, except in so far as it affects the structure of the scale, has no direct influence on its heat transmitting qualities."

A thick scale may cause overheating by preventing radiation, rapid deterioration, and even blistering and cracking of boiler tubes and shells.

When the chemical analysis of a boiler water is at hand, its scale-forming properties can readily be determined. In this connection the formulæ developed by Stabler[31] are of special value:

Scale (in pounds per 1,000 gallons of water) $= 0.00833$ suspended matter $+ 0.0083$ colloidal matter ($= SiO_2 + Al_2O_3 + Fe_2O_3$) $+ 0.0107Fe + 0.0157Al + 0.0138Mg + 0.0246Ca$.

[29] Palmer, *U. S. Geol. Surv., Water-Supply Paper* (1909), 233, 186.
[30] *Bull. Univ. Ill.* (1907), 4, No. 15, 1.
[31] *U. S. Geol. Surv., Water-Supply Paper* (1911), 274, 176.

The preceding formula shows the total amount of solids (scale and sludge) precipitated under ordinary conditions.

The amount of matter deposited as a hard scale will be: $0.00833SiO_2+0.0138Mg+(0.016Cl+0.0118SO_4-0.0246Na-0.0145K)$.

Though scale is a serious menace to boiler tubes and shell, a very thin scale may sometimes be advantageous in a boiler, especially when a corrosive water is being used. Kent[32] recommends the occasional addition of lime water to water of this kind, so that the resulting thin scale may protect the boiler.

WATER SOFTENING AND SCALE PREVENTION

For most technical and industrial work a water low in mineral content is generally desired. In many localities such water is not available, and the existing supply must be softened to make it suitable for use. The scale-forming ingredients of water may easily be reduced to 50 parts per million by careful treatment. When a boiler plant is supplied with impure water, either the formation of hard scale must entirely be prevented and the soft scale and sediment blown off or the plant must be in two parts, one the boiler proper and the other the purifying apparatus which is so far as possible independent of the boiler and in which chemical precipitation of the scale-forming ingredients takes place where it will do no harm. As hardness is generally due to salts of calcium and magnesium, the main problem of water softening is to precipitate these salts as completely and as cheaply as possible, without introducing any ingredient injurious to the water. The cost of any process or method for the treatment of a boiler feed supply depends to a large extent upon the chemistry of the water to be treated. No one reagent is known which will remove the scale-forming ingredients from all waters, although almost everything from soda to catechu has been proposed and tried. Calcium carbonate held in solution in water by excess of carbonic acid may be precipitated by removing the carbon dioxide by boiling or by the addition of lime.

Calcium carbonate is practically insoluble, and therefore the reaction proceeds practically to completion. Magnesium carbonate reacts similarly, but owing to its slight solubility the reaction does not proceed to completion, and in order to remove it completely a further quantity of milk of lime must be added.

The completeness of the precipitation of calcium carbonate is the same whether water is boiled under atmospheric pressure or under a pressure of several atmospheres. The completeness of the precipitation of magnesium carbonate, however, is increased by increasing the pressure.[33] Freshly precipitated calcium carbonate settles very slowly, especially when obtained by treating the bicarbonate with milk of lime in the cold, so that the precipitation must be made in large tanks where the treated water can remain a long time undisturbed. Heat hastens the settling. By properly handling such a water in a boiler, a loose powdery sediment is obtained which may be removed by blowing off, but if sulphates are present it is deposited as hard scale. If sulphates are present, the chemical precipitation should be carried on outside of the boiler.

The amount of the sulphate ion in boiler waters is important on account

[32] *Loc. cit.*

[33] Knight, N., *Eng. News* (1905), 53, 311.

of the scale-forming propensity of calcium sulphate. Calcium sulphate is removed by the use of soda ash thus:

$$CaSO_4+Na_2CO_3 \leftrightarrows CaCO_3\downarrow+Na_2SO_4.$$

Sodium carbonate added to magnesium salts precipitates basic magnesium carbonate $Mg(OH)_2MgCO_3$ and liberates carbon dioxide. One of us[34] has shown that this precipitation is not complete and that both sodium chloride and sodium sulphate either at ordinary temperature or at boiling render this more incomplete.

To precipitate magnesium as completely as possible, one must add both soda ash and lime according to the equation

$$MgSO_4+Na_2CO_3+Ca(OH)_2 \leftrightarrows Mg(OH)_2\downarrow+CaCO_3\downarrow+Na_2SO_4.$$

When the carbonate and sulphate of lime are both present as in some waters, sodium hydroxide is all that is necessary practically to precipitate completely both of the salts as shown by the following equation:

$$CaH_2(CO_3)_2+CaSO_4+2NaOH \leftrightarrows 2CaCO_3+Na_2SO_4+2H_2O.$$

Of all the reagents used as coagulants, it is probable that sodium hydroxide gives the best results in the majority of waters. Sodium sulphate (Na_2SO_4) is very soluble, and is unobjectionable in quantities such as usually result from the chemical precipitation of the scale-forming ingredients of water. The use of alum in boiler feed waters is very old. It is used to coagulate the impurities where mechanical filtration is used, and has been thought to reduce the quantity of scale formed. As a scale preventive it is undesirable unless used outside the boiler in a settling tank, for it reacts with some of the calcium carbonate present, which otherwise would give a soft scale, converting calcium carbonate into calcium sulphate which forms a very hard injurious scale. Alum and sodium hydroxide are sometimes used together. The reaction which takes place may be represented by

$$K_2Al_2(SO_4)_4+8NaOH=3Na_2SO_4+K_2SO_4+4H_2O+Al_2O_4Na_2$$

in which sodium aluminate is formed and in turn reacts on the salts of calcium, magnesium, and iron to give aluminates of the corresponding metal and an equivalent amount of sodium salts in the water.[35] The reactions involved in the precipitation are

$$CaH_2(CO_3)_2+Al_2O_4Na_2+H_2O=CaCO_3+2Al(OH)_3+Na_2CO_3$$

and

$$CaSO_4+Na_2CO_3=CaCO_3+Na_2SO_4.$$

Seven different waters were tested by this method and also by sodium hydroxide alone, but in each case the latter removed only about one-half the quantity of lime that was thrown out by the aluminate. The precipitated alumina also removed suspended matter most completely.

One of the newer methods of softening water which deserves mention is the "Permutit" process,[36] in which a large excess of an insoluble purifying agent is used instead of a small amount of a soluble one. "Permutit" is made by heating feldspar, kaolin, clay, and soda in definite proportions to form, presumably, $2SiO_2 \cdot Al_2O_3 \cdot Na_2O \cdot 6HO$. Hard water passed rapidly

[34] Stillman and Cox, *Journ. Am. Chem. Soc.* (1903), **25**, 734.

[35] Mabery, Chas. F., and Baltzley, E. B., *Journ. Am. Chem. Soc.* (1899), **21**, 23.

[36] *Glückauf* (1911), **47**, 982.

through a comparatively thin layer comes out thoroughly softened. The substance may be regenerated by treatment with warm 10 per cent salt solution. The cost of softening water by this method is about 1.25 to 1.5 centavos per cubic meter.

Crude oil has been suggested to assist in the prevention of scale in steam boilers, but it is injurious in that its residual tar combines with the sediment to form an undesirable scale. Kerosene has been used in the prevention of scale without deleterious results,[37] because this is the fraction of crude petroleum from which the naphtha or volatile products have been removed in the process of refining and it has no residual product. The action in this case is mostly mechanical in that it forms a protective greasy film over the interior boiler parts and greases the precipitated matter so that it does not coagulate but remains in suspension, in which condition it can be blown off easily. Kerosene is very satisfactory as a scale preventive, but it should be handled with care, and it must be remembered that it will attack the rust and open up leaky parts and is apt to be carried in the steam in sufficient quantity to injure the rubber packing of the engine and of all valves. Tannin and other wood extracts are excellent scale preventives in that they cause the precipitate to form as soft scale or sediment that can be easily removed from a boiler by blowing off. On the other hand, some wood extracts contain acid in sufficient quantity to attack the metal of the boiler.

Of the chemical softeners, soda ash (crude sodium carbonate) and lime are the ones most widely used. From the chemical analysis of the water, the necessary amounts of each of these can readily be calculated.

According to Stabler[38] the number of pounds[39] of 90 per cent lime (CaO) required$=0.00931Fe + 0.0288Al + 0.0214Mg + 0.258H + 0.00426 HCO_3 + 0.0118CO_2$; and the number of pounds of soda ash (95 per cent Na_2CO_3) $=0.0167Fe + 0.0515Al + 0.0232Ca + 0.0382Mg + 0.462H - 0.0155CO_3 - 0.00763HCO_3$ for every 1,000 gallons[40] of water.

CORROSION

There are many causes of corrosion, and a substance which may resist one cause may readily yield to another. Boiler corrosion does not necessarily depend on the quality of the boiler plate; in fact, steel often corrodes more quickly than wrought iron.[41] Continued or interrupted use of a properly cared for boiler has little to do with corrosion, but when not properly cared for a boiler in continued use will not corrode as rapidly as one in interrupted use. Stabler[42] has calculated the "coefficient of corrosion," $c=H + 0.1116Al + 0.0361Fe + 0.0828Mg - 0.0336CO_3 - 0.0165HCO_3$. If c is positive, the water will certainly corrode a boiler. If $c+0.0503$ Ca is negative, the mineral constituents in the water will not cause corrosion. If c is negative but $c+0.0503$ Ca is positive, corrosion may or may not occur, the probability of corrosive action varying directly with the value of the expression $c+0.0503$ Ca.

All natural waters contain oxygen in solution, and this is continually being introduced into the boiler by means of the feed pump and often

[37] Lyne L. F., *Trans. Am. Soc. Mech. Eng.* (1888), **10.**

[38] *U. S. Geol. Surv., Water-Supply Paper* (1911), 274, 170.

[39] 1 pound=0.45359 kilogram.

[40] 1 U. S. gallon=3.78543 liters.

[41] *Eng. News* (1903), **50**, 286, 296, and 502.

[42] *Loc. cit.*, 175.

produces corrosion at the point of discharge. In badly designed boilers, oxygen introduced in this way together with the air left in the boiler is apt to accumulate in pockets due to improper circulation and is capable of causing the corrosive action, technically known as pitting because of the small holes or "pits" found in the damaged area. Pitting is the most dangerous form of corrosion. The presence of carbon dioxide together with the oxygen in a boiler water increases its corrosive action. Cases have been known where the mixing with air of hydrogen sulphide and carbon dioxide produced by the decomposition of sewage entering a water supply have caused very rapid corrosion.

The use of alum for coagulation in mechanical filtration is sometimes bad, for alum may react with bicarbonates to change them into sulphates and thus liberate carbon dioxide and cause corrosion of the boiler. A feed water which contains considerable quantities of magnesium salts when purified by sodium carbonate alone will liberate carbon dioxide as represented by the following equation:

$$MgSO_4+MgCl_2+2Na_2CO_3+H_2O \leftrightarrows Mg(OH)_2MgCO_3+ Na_2SO_4+2NaCl+CO_2.$$

Schreiber[43] calls attention to the corrosive action of such a water on a boiler especially in the region of the intake. In the absence of air, iron is only slightly attacked by an excess of carbon dioxide.[44]

The rusting of iron in the presence of air is much more energetic when in contact with water containing chlorides (NH_4Cl, $MgCl_2$, KCl, NaCl, $CaCl_2$, $BaCl_2$).[45] Magnesium chloride, while not a scale-forming ingredient, is accepted as an exceptionally active corrosive agent. Sometimes the water is red or black, which in either case is evidence that energetic corrosion is in progress. It often happens that there is pitting over the entire inner surface of the boiler, but again it may be local in its action. It sometimes has been explained that magnesium chloride is much more injurious than the other chlorides through the hydrolytic splitting off of hydrochloric acid.[46] Magnesium chloride cannot split off acid without simultaneously forming a basic magnesium compound. The injurious corrosion resulting from the presence of magnesium salts is not due to reaction of free acid but to the interaction of the salts themselves. Ost,[47] working experimentally in the absence of air and under a steam pressure of about 10 atmospheres, has shown that with boiler plate in contact with pure water or waters containing about 5 per cent of magnesium chloride, potassium chloride, sodium sulphate, potassium sulphate, calcium sulphate, and magnesium sulphate, respectively, there is rusting in all cases. That is, after each trial the interior of the experimental boiler was covered with an amount of ferrosoferric oxide (Fe_3O_4) which he attributed to the oxidation of iron through the decomposition of the hot feed water.[48] Only when magnesium salts

[43] *Chem. Zeitg.* (1903), 27, 327.

[44] Howe, J. L., and Morrison J. L., *Journ. Am. Chem. Soc.* (1899), 21, 422.

[45] Wagner, A., *Dingler's polytech. Journ.* (1875), 218, 70.

[46] The action of chlorides on copper is quite different, for the latter forms double salts with chlorides and in this way goes into solution.

[47] *Chem. Zeitg.* (1902), 26, 819, 845.

[48] It is a well-known reaction that oxygen interacts vigorously with iron and similar metals when the latter is at a red heat. The slow reaction which involves the decomposition of water is of even greater interest.

were present did any iron go into solution. The action began at about 100°, and the evolution of hydrogen was most pronounced when calcium and potassium chlorides and potassium and sodium sulphates were used, which indicates that the rusting in the magnesium chloride solution was not the result of splitting off hydrochloric acid. The magnesium salt reacts with the oxidized iron to form a soluble salt of the latter, while the magnesium is precipitated as hydroxide. Within certain limits this reaction is reversible, and in no case will it proceed until all of the magnesium salt is precipitated. When equilibrium is attained, no more iron will be dissolved until a new supply of magnesium salt is introduced or the equilibrium disturbed in some other manner.

The view that magnesium chloride does not have the highly corrosive action generally attributed to it is further corroborated by Bradbury,[49] who found that magnesium chloride, either in cold or hot solution, would not attack iron at atmospheric pressure.

Röhrig and Treumann[50] have shown that at high pressures magnesium salts and calcium carbonate interact to precipitate hydrated magnesium oxide. When a 0.5 per cent water solution of magnesium chloride is employed, it is possible to precipitate 63.3, 83.1, and 100 per cent of the magnesium oxide present under a pressure of 5, 10, and 15 atmospheres, respectively.

Ost found that at a pressure of 10 atmospheres the equilibrium soon established itself and even at lower pressure the carbon dioxide liberated soon escaped with the steam. The interaction was not complete, but a sufficient quantity of the magnesium is precipitated in the mud to stop the solution of iron.

The presence of free acid in hot water in more than 40 or 50 parts per million is apt to cause serious corrosion of a boiler or any metal parts with which it comes in contact. The action of acid due to grease which, in spite of all precautions, finds its way into a boiler is sometimes the cause of serious difficulty. The presence of acid-free volatile oil can do no harm in a boiler. On the contrary, besides assisting in preventing scale it is useful in reducing the rusting. For the treatment of acid mine waters, $Ba(OH)_2$ is the most serviceable reagent.[51]

Electrolytic action is sometimes the cause of corrosion. When there is a difference of potential between different parts of a system immersed in an electrolyte, electrochemical action is set up at the expense of the more electropositive element; for example, if brass feed or internal pipes were used in contact with iron, the iron would disintegrate rapidly. In spite of this fact, it is common practice to use brass or copper piping for feed pipes. Impurities in iron, as carbon or slag, would have the same injurious effect. But the presence of a more electronegative substance is not necessarily the only cause of electrochemical corrosive action. Strain, distortion of any part, lack of homogeneity, or even a difference in temperature between portions of the same piece of metal may cause differences of potential and greatly accelerate corrosion. From electrochemical considerations the corrosive action of acid waters is also readily explained. Iron, which is electropositive to copper, will precipitate the latter from

[49] *Chem. News* (1913), **108**, 307.

[50] *Zeitschr. f. öff. Chem.* (1900), **6**, 241–3.

[51] Griffin, M. L., *Journ. Am. Chem. Soc.* (1899), **21**, 665.

solutions of its salts, the iron going into solution at the same time. In the same manner, acid hydrogen, being negative to iron, is liberated and iron is dissolved (corroded).

Stray currents are another important factor influencing corrosion. At best proper insulation is a difficult problem in any city, but it is especially difficult in Manila, where the heavy rains keep the ground saturated four or five months in the year. Here many cases have been found in which excessive corrosion of boilers has been accompanied by appreciable differences of potential between boiler parts and surrounding objects.

Corrosion may be avoided in a variety of ways. Corrosive ingredients may be eliminated by proper chemical treatment. Iron does not corrode readily in the presence of alkalies, hence the addition of soda ash or lime to water is beneficial. Since iron is attacked electrolytically only when it is the anode, any method whereby it is made the cathode will prevent corrosion. Zinc is electropositive to iron, and hence when connected with it will make the iron the cathode of an electrolytic cell. It corrodes very easily, and is now very satisfactorily in use to protect the internal parts of boilers and condenser tubes on steamers from electrolytic corrosion.[52]

Rather recently the suggestion has repeatedly appeared[53] to make iron the cathode by impressing an electromotive force from the outside counteracting many internal currents which might tend to destroy the iron. Another method of inhibiting corrosion takes advantage of the passive state of iron. As is well known, iron, under the influence of certain chemicals, notably oxidizing agents, becomes passive and resistant to ordinary forms of attack. The addition of 1 kilogram of potassium dichromate ($K_2Cr_2O_7$) to 12.5 metric tons of water should prevent corrosion.[54]

FOAMING AND PRIMING

Foaming is the formation of an aggregation of bubbles on the surface of the water of a boiler. Sometimes the bubbles which constitute the foam are durable and remain for a long time without breaking; when formed in rapid succession, they entirely fill the steam space and pass along with the steam. When this is the case, a boiler is said to prime. In passing through the steam pipe the bubbles become broken up and are carried into the cylinder as hot water.

The priming tendency is influenced by the steam space and the design of the boiler, and in general increases as the steam space diminishes. A boiler ordinarily supplying dry steam may prime heavily under an overload.

Some of the causes of foaming are the presence of sodium and potassium salts in quantity, mud, organic and suspended matter, or any material

[52] "It may perhaps pay to prevent the corrosion of steel docks by connecting them with a plate or block of zinc. In this way the oxidation of the iron can be prevented, although the zinc will of course be destroyed. Aluminium theoretically should be better than zinc, but has not proved so satisfactory in practice probably on account of the oxide film which is always formed on an aluminium surface."—*Electrochem. & Met. Ind.* (1903), 1, 318.

[53] Cf. Clement and Walker, *Tech. Paper, U. S. Bur. Mines* (1913), No. 15.

[54] *Electrochem. & Met. Ind.* (1907) 5, 363.

on the surface of the water which prevents free escape of the steam. Salts in solution increase the surface tension of the water and thereby prevent the free escape of steam. The chief of the undesirable alkali salts are sodium chloride, sodium sulphate, and sodium carbonate. The first is the chief constituent of sea water, and is frequently found in artesian water when wells are driven near the ocean; usually, sodium sulphate and often sodium carbonate are the most abundant substances present in softened waters. In small quantities these do no harm, but where the water is very hard they constitute an important factor. For instance, in the southwestern portion of the United States the amounts of alkali carbonate and sulphate resulting from the softening process is very great. On this account some wells along railway lines had to be abandoned. On account of their limited steam space, locomotive boilers will foam with from 1 to 3 per cent of sodium salts, while stationary boilers where the steam space is much greater have been run successfully without foaming with 12 per cent.

Mud and organic and suspended matter may be permanently removed by filtration. No practical way has been devised to get rid of sodium salts. Foaming is a surface condition, and temporary relief from it, no matter what the cause, may be had by surface blowing. Mineral oil is sometimes injected into boilers to reduce the surface tension of the bubbles and thus prevent priming. The only remedy from foaming on account of excessive salts is by blowing off and reducing the concentration. To blow off hot and pump in cold water is, of course, very uneconomical, and should be resorted to as little as possible. Furthermore, with excessive blowing off a greater quantity of water is consumed and if the feed water contains scale-forming ingredients the amount of scale formed is increased.

MINERAL WATER SUPPLIES

The best water for human consumption is probably that which is as free as possible from organic matter and which contains only in relatively small amounts the normal mineral ingredients of natural water. The amounts of mineral matter may generally, however, be varied within wide limits without producing marked physiologic effects. Water which is well aërated and the mineral content of which is below 300 parts per million is generally considered to have the best taste. Water which contains more than about 1,000 parts per million of mineral matter in solution is liable to prove laxative or to have an exceptional taste, although many waters, notably the waters from mineral springs, often containing over 2,000 parts per million, are used constantly without deleterious effects.

A moderately hard water is usually to be preferred to a very soft one. Much evidence has been brought forward to show that the health of people living in localities where hard water is used is better than that of people using only soft water. For example, Berg and Röse [55] conclude that there are fewer bad

[55] *Biochem. Zeitschr.* (1910), 27, 204.

teeth among users of hard water; also, that the nursing period of mothers lasts longer.

The term "mineral water" is somewhat confusing. Practically all natural waters contain dissolved mineral matter, and might properly be classified as "mineral waters." However, in the more restricted meaning of the term, only those waters are included which have peculiar characteristics distinguishing them from ordinary spring or well water. According to L. Grünhut,[56] a mineral water is differentiated by (*a*) a high content of soluble matter, (*b*) a high content of rare or unusual substances, or (*c*) a high temperature. The following are the substances on the basis of which he makes his classification and the limiting values for each substance:

Substance.	Parts per million.
Total solids	1,000
Free carbondioxide	250
Lithium ion ($Li^{\bullet}$)	1
Strontium ion ($Sr^{\bullet\bullet}$)	10
Barium ion ($Ba^{\bullet\bullet}$)	5
Ferrous or ferric ion ($Fe^{\bullet\bullet}$ resp. $Fe^{\bullet\bullet\bullet}$)	10
Bromine ion (Br')	5
Iodine ion (I')	1
Fluorine ion (F')	2
Hydroarsenate ion ($HAsO''_4$)	1.3
Metaarsenious acid ($HAs\ O_2$)	1
Total sulphur	1
Metaboric acid (HBO_2)	5

Alkalinity	4 (equivalent to 0.34 gram of $NaHCO_3$ per liter).
Radium emanation	3.5 Mache units per liter.
Temperature	20° C.[a]

[a] Obviously this value could not be used in a country like the Philippines, where in many localities the average temperature is much higher and water is usually from 25° to 30° C.

If any of these values[57] is exceeded, the corresponding water may be regarded as a mineral water. The curative properties sometimes attributed to various mineral springs appear grossly exaggerated, and it hardly seems plausible that the small amounts of mineral salts contained in such waters should have the wonderful power ascribed to them. No doubt the pleasant surroundings of the average medicinal spring resort, combined with fresh air, good food, and general relaxation and exercise, contribute their share toward the improvement in the health

[56] *Zeitschr. Balneol.* (1912), **4**, 433–6; *Wasser u. Abwasser* (1912), **5**, 417–20; *Pharm. Zentralh.* (1914), **55**, 180.

[57] This classification has been adopted by the Verein der Kurorte und Mineralquellen-Interessenten Deutschlands, Oesterreich-Ungarns und der Schweiz.

of a patient and help make possible the remarkable cures often recorded. It is not the purpose of this paper to go into any discussion of the medical value of different mineral medicinal waters. Haywood and Smith[58] have published a classification of mineral waters, showing their physiologic action and therapeutic applications.

There are a large number of mineral and thermal springs in the Philippine Islands, many of which are located in places admirably suited for health resorts. At the present time the springs at only three places are much visited; namely, near Baguio, at Los Baños, and at Sibul. However, there are a large number of springs which were well known in Spanish times and which, with proper exploitation, would undoubtedly again become popular.

The systematic study of the mineral waters of the Philippine Islands is still far from complete. The Spanish Government instituted a rather elaborate series of investigations concerning Philippine mineral waters, the results of which have already been published.[59]

At the request of the Speaker of the Philippine Assembly, an investigation of the mineral springs of Cebu was conducted by Mr. Gana of the Bureau of Science. The results of his work are incorporated in Table VIII.

Though some preliminary work has been done on the radioactivity of Philippine waters, this subject still remains practically untouched.[60] It is hoped that in the near future it will be possible to devote time to this field of investigation.

The analyses of mineral spring waters examined at the Bureau of Science are given in Table VIII. The sanitary analyses of many of these waters have already been given in Table IV. In Table VIII are included all waters of which mineral analyses have been made, regardless of whether such waters are properly classified as mineral water or not. With regard to the naming of mineral waters according to their prominent constituents, the classification of Peale, as modified by Haywood and Smith,[61] has been used throughout.

[58] Mineral Waters of the United States. *Bull. U. S. Dept. Agr., Bur. Chem.* (1905), 91, 12.

[59] Centeno, J., del Rosario y Sales, A., y de Vera y Gomez, J., Memoria descriptiva de los manantiales minero-medicinales de la Isla de Luzon. Madrid (1890). Casariego, E., y de Vera y Gomez, J., Estudio descriptivo de algunos manantiales minerales de Filipinas. Introduction by A. de Aviles. Manila (1893).

[60] Bacon, *This Journal, Sec. A* (1906), 2, 122.

[61] *Loc. cit.*, 9.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	117427.	60883–I.
Date	October, 1913	December, 1908
Locality	Agusan, Aspetia	Albay, Tancalao, Tabaco
Source	Spring	Spring
Physical properties		Yellow
Reaction		Acid
Total solids		
Silica (SiO_2)	47.5	101.2
Sulphuric acid radicle (SO_4)	455.9	2,129.3
Bicarbonic acid radicle (HCO_3)		
Carbonic acid radicle (CO_3)		
Nitric acid radicle (NO_3)		
Nitrous acid radicle (NO_2)		
Phosphoric acid radicle (PO_4)		Trace
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	7,176.47	Little
Bromine (Br)		
Iodine (I)		
Iron (Fe)		251.895
Aluminium (Al)		90.0135
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	11.0	
Manganese (Mn)		9.366
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	1,161.5	258.80
Magnesium (Mg)	4.4	75.47
Potassium (K)	16.1	16.762
Sodium (Na)	3,659.0	44.548
Lithium (Li)	Nil	Trace
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification		
Remarks		

springs and other sources as noted.

parts per million.]

Laboratory No.			
60883–II.	61021.	61022.	115731.
December, 1908	December, 1908	December, 1908	August, 1913.
Albay, Tancalao, Tabaco.	Albay, Tiwi	Albay, Tiwi	Albay.
Spring	Mineral spring	Mineral spring	Tiwi Spring.
Yellowish	Turbid; clayish sediment.	Clear	Normal.
Acid			Acid.
			180.8.
90.4	65.6	75.8	73.6.
1,141.6	34.56	31.06	29.1.
	64.26	78.39	57.9.
			Nil.
	Nil	Trace	Nil.
	Nil	Nil	Nil.
Nil	Trace	Trace	Nil.
Trace	Small amount	Trace	
Nil	Nil	Nil	
Little	4.455	3.96	4.45.
Nil	Nil	Nil	
Nil	Nil	Nil	
117.785			
39.5623			
	2.00	2.5	2.4.
11.168	Trace	Nil	
Nil	Trace		
Nil	Trace		
151.18	114.65	15.37	17.1.
28.44	5.85	5.96	5.4.
10.315	7.495	5.6	4.6.
23.974	12.79	13.82	11.6.
Trace			Nil.
	0.3528	0.0041	

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	61023.	115071.
Date	December, 1908	November, 1913
Locality	Albay, Albay Gulf	Ambos Camarines, Lanot.
Source	Thermal spring[a]	Lanot Spring
Physical properties	Somewhat brownish, turbid.[b]	See remarks
Reaction	Acid	Neutral
Total solids		654.4
Silica (SiO_2)	329.8	160.4
Sulphuric acid radicle (SO_4)	87.64	22.5
Bicarbonic acid radicle (HCO_3)		276.9
Carbonic acid radicle (CO_3)		Nil
Nitric acid radicle (NO_3)	Nil	Nil
Nitrous acid radicle (NO_2)	Nil	Nil
Phosphoric acid radicle (PO_4)	Nil	Trace
Metaboric acid radicle (BO_2)	Little	Nil
Arsenic acid radicle (AsO_4)	0.4865	Nil
Chlorine (Cl)	5,183.16	155.8
Bromine (Br)	8.14	Nil
Iodine (I)	0.079	Nil
Iron (Fe)		17.4
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	6.0	
Manganese (Mn)	3.24	2.2
Barium (Ba)	0.470	Nil
Strontium (Sr)		Nil
Calcium (Ca)	220.2	42.0
Magnesium (Mg)	4.15	24.5
Potassium (K)	246.44	Little
Sodium (Na)	2,998.66	109.5
Lithium (Li)	Trace	Nil
Ammonium (NH_4)	6.39	
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		Ferruginous carbon dioxated.
Classification		
Remarks		(c)

[a] On south shore of Albay Gulf.
[b] Has a reddish sediment.
[c] Clear and colorless. Becomes yellow-brown and turbid on exposure.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
12568.	9704–II.	9704–III.	47089.
November, 1904	June, 1904	June, 1904	July, 1907.
Ambos Camarines, Pascao.	Ambos Camarines, Goa.	Ambos Camarines, Pasacao.	Babuyanes, Camiguin Island.
"Punta Mainit" Spring.	"Lalo" Spring, Lagonoy.	"Punta Mainit" Spring near Pasacao.	Hot spring, SW. coast.
	Slate color ; turbid	Clear	
Alkaline	Alkaline	Neutral	
505.00	1,908.00	526.00	20,092.6.
46.50	130.60	48.40	178.6.
32.09	79.21	32.50	
	Considerable	Small amount	
52.25	404.00	53.00	
	6.29	Trace	
			12.2.
	Trace	Trace	
	Trace		
51.20	218.72	51.75	410.836.
27.20	79.02	30.78	419.93.
	Trace		694.627.
87.90	354.91	101.44	5,914.18.
	Trace		
	Trace	Trace	
		Lead 2.77	

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	47090.	115732.
Date	July, 1907	August, 1913
Locality	Babuyanes, Camiguin Island.	Batangas, Gapas, Balayan.
Source	Hot spring, south coast	Spring
Physical properties		
Reaction		Alkaline
Total solids	5,720.7	601.6
Silica (SiO_2)	173.8	114.0
Sulphuric acid radicle (SO_4)	1,449.24	32.0
Bicarbonic acid radicle (HCO_3)		414.3
Carbonic acid radicle (CO_3)		Nil
Nitric acid radicle (NO_3)		Nil
Nitrous acid radicle (NO_2)		
Phosphoric acid radicle (PO_4)		Nil
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)		57.9
Bromine (Br)		
Iodine (I)		
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)		2.4
Manganese (Mn)		
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)		58.6
Magnesium (Mg)		34.2
Potassium (K)		9.2
Sodium (Na)		35.5
Lithium (Li)		Nil
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification		
Remarks		([a])

[a] Sodic, bicarbonated, alkaline, siliceous.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
788.	789.	790.	90174.
September, 1902. Benguet, "Sanitarium" Spring.	September, 1902. Benguet, "Bued River Spring."	September, 1902. Benguet, "Loo Spring."	September, 1911. Benguet, Klondike Spring.
A little sediment	A little sediment	A little sediment	
112.00	49.3	685.6	
Small amount	Small amount	Small amount	40.9.
	7.80	323.6	348.6.
			21.3.
Trace	Trace	Small amount	Nil.
			Trace.
Trace	Trace	Trace	588.0.
Trace	None	Trace	
			Trace.
			Nil.
Small amount	Trace	Considerable	134.0.
Small amount	Small amount	Considerable	Trace.
			Trace.
			388.2.

TABLE VIII.—*Analysis of waters from mineral*

[Numbers give

	Laboratory No.	
	101638.	18654–I.
Date	May, 1912	July, 1905
Locality	Benguet	Bataan, Dinalupihan
Source	([a])	Hot spring
Physical properties	Spring	Suspended organic matter.[b]
Reaction	Alkaline	Alkaline
Total solids		1,880
Silica (SiO_2)	185.4	117.2
Sulphuric acid radicle (SO_4)	425.3	52.8
Bicarbonic acid radicle (HCO_3)	491.6	415
Carbonic acid radicle (CO_3)	Nil	
Nitric acid radicle (NO_3)		
Nitrous acid radicle (NO_2)		
Phosphoric acid radicle (PO_4)		
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	988.2	650.0
Bromine (Br)		
Iodine (I)		
Iron (Fe)		Trace
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	12.8	
Manganese (Mn)	3.5	
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	474.6	83.4
Magnesium (Mg)	61.1	92.0
Potassium (K)	41.6	
Sodium (Na)	626.3	424.0
Lithium (Li)		
Ammonium (NH_4)		Trace
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)	20.5 cc. per liter	29.7
Classification		
Remarks		

[a] Antamok River Spring.

[b] In small amount. Slight, disagreeable, foul odor.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
18654–II.	18654–III.	9704–I.	56698–I.
July, 1905	July, 1905	June, 1904	March, 1909.
Bataan, Dinalupihan	Bataan, Dinalupihan	Bulacan, Sibul	Bulacan, Sibul.
Spring	Spring	Spring	Spring.
Suspended organic matter.[b]	Suspended organic matter.[b]	Slight, white sediment	
Alkaline	Alkaline	Neutral	Alkaline.
2,200	676	534.0	536.20.
112.4	108.4	15.20	81.40.
57.6	9.4		4.50.
345	237		
			Nil.
			Trace.
760.0	140.0	34.0	23.40.
Trace	Trace		
		Trace	0.40.
		Trace	
92.0	28.7	147.82	149.
97.0	26.0	16.06	15.30.
			0.14.
435.0	140.0	30.22	19.80.
			Trace.
Considerable	Present		
22.00			
			(d)
	(c)	Lead, 12.29 c	

c Small amount of carbon dioxide.
d Calcic, saline.

TABLE VIII.—*Analysis of waters from mineral*

[Numbers give

	Laboratory No.	
	56698–II.	56698–III.
Date	March, 1909	March, 1909
Locality	Bulacan, Sibul	Bulacan, Sibul
Source	Bottom of spring	Surface of spring
Physical properties		
Reaction	Alkaline	Alkaline
Total solids	507.80	501.20
Silica (SiO_2)	45.40	41.20
Sulphuric acid radicle (SO_4)	2.40	3.70
Bicarbonic acid radicle (HCO_3)		
Carbonic acid radicle (CO_3)		
Nitric acid radicle (NO_3)	Nil	Nil
Nitrous acid radicle (NO_2)	Trace	Trace
Phosphoric acid radicle (PO_4)		
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	25.28	24.40
Bromine (Br)		
Iodine (I)		
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	0.20	0.90
Manganese (Mn)		
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)		147.70
Magnesium (Mg)	15.39	15.39
Potassium (K)	1.10	1.10
Sodium (Na)	23.57	22.20
Lithium (Li)	Trace	Trace
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification	([a])	([a])
Remarks		

[a] Calcic, saline.

[b] With slight odor of sulphureted hydrogen and sulphureted alkaline taste.

springs and other sources as noted—**Continued.**

parts per million.]

Laboratory No.			
56698–IV.	66195.	69012.	74181.
March, 1909	December, 1908	July, 1909	January, 1910.
Bulacan, Sibul	Bulacan, Marilao	Bulacan, Hagonoy	Bulacan, Hagonoy.
Bath	Artesian well	Well 1	Well 3.
	Very slightly brown [b]		
Alkaline	Alkaline	Alkaline	
498.00			
41.00	29.60	44.3	36.1.
4.00	8.43	49.88	263.12.
	161.69	425.16	139.99.
	8.64		
Nil	Nil	Nil	Trace.
Trace	Nil	0.1327	1.541.
	Nil	Trace	Nil.
	Trace	Trace	Trace.
	Nil	Nil	
24.60	12.1	104.56	287.24.
	Nil	Nil	Nil.
	Nil	Nil	Trace.
0.60	0.75	1.25	0.25.
	Nil	Trace	1.08.
	Nil		Nil.
	Nil		Nil.
148.90	2.14	14.473	43.95.
14.92	0.21	10.01	21.55.
1.30	2.94	4.84	14.87.
23.30	78.86	213.4	277.14.
Trace	Nil	Nil	
	0.0716	0.551	0.547.
(a)		(c)	(d)

[c] Sodic, bicarbonated, alkaline, siliceous.
[d] Sodic, sulphated, saline.

TABLE VIII.—*Analysis of waters from mineral*

[Numbers give

	Laboratory No.	
	116873.	13198.
Date	September, 1913	September, 1904
Locality	Capiz, Sohut, Dumalag	Cavite, U. S. N. station
Source	Spring	From artesian well 158.4 meters deep.
Physical properties	Green	
Reaction	Neutral	Alkaline
Total solids	528.0	476.0
Silica (SiO_2)	20.8	72.0
Sulphuric acid radicle (SO_4)	18.9	26.40
Bicarbonic acid radicle (HCO_3)	373.3	
Carbonic acid radicle (CO_3)	Nil	
Nitric acid radicle (NO_3)	Nil	
Nitrous acid radicle (NO_2)	Nil	
Phosphoric acid radicle (PO_4)	Nil	
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	105.39	57.12
Bromine (Br)		
Iodine (I)		
Iron (Fe)		Trace
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	3.7	
Manganese (Mn)		
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	61.95	3.57
Magnesium (Mg)	27.9	Trace
Potassium (K)	Very little	
Sodium (Na)	94.6	150.34
Lithium (Li)	Nil	
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification	([a])	([c])
Remarks	([b])	

[a] Sodic, bicarbonated, muriated, alkaline, sulphureted.

[b] Odor of hydrogen sulphide.

[c] Contains carbonates and bicarbonates.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
86357.	88381.	53251.	53252.
March, 1911	June, 1911	December, 1907	December, 1907.
Cavite, U. S. N. station.	Cavite, U. S. N. station.	Cebu, "Maaslom" Spring.	Cebu, "Malanza" Spring.
U. S. N. station water system.			Spring.
	Slightly brownish		
Acid	Alkaline	Acid	Acid.
41.8	484.6		
	97.45	165.9	90.1.
3.395	25.51	613.38	233.5.
33.48	210.4		
Nil	18.0		
Nil	Nil	1.77	4.25.
Nil	Nil	Nil	Nil.
Nil	1.342		
Trace	Nil	Nil	Nil.
Nil		Nil	Nil.
		7.5	12.8.
Nil	Nil	Nil	Nil.
Nil	Nil	Faint trace	Nil.
		0.44	0.43.
		70.1	6.56.
	1.00		
Nil	Nil	0.9	Trace.
		Nil	Nil.
		Nil	Nil.
5.539	5.18	30.54	11.61.
1.148	1.20	38.26	28.43.
0.738	15.69	1.42	13.82.
2.959	141.73	22.82	19.01.
Nil	Nil	Nil	Nil.
		0.4602	1.066.
		106.78[a]	29.88.[a]
	([e])	([f])	
([d])			

[d] Acidity is due to free carbon dioxide.
[e] Sodic, bicarbonated, alkaline, siliceous.
[f] Aluminic, sulphated, acidic, siliceous.

TABLE VIII.—*Analysis of waters from mineral*

[Numbers give

	Laboratory No.	
Date	October, 1910	October, 1910
Locality	Cebu, Mainit, Naga	Cebu, Mainit, Naga
Source	North Spring	South Spring
Physical properties	Saline taste [a]	Saline taste [a]
Reaction		
Total solids		
Silica (SiO_2)	95.85	98.00
Sulphuric acid radicle (SO_4)	231.6	236.95
Bicarbonic acid radicle (HCO_3)	294.2	294.28
Carbonic acid radicle (CO_3)		Nil
Nitric acid radicle (NO_3)	Trace	Trace
Nitrous acid radicle (NO_2)	Trace	Nil
Phosphoric acid radicle (PO_4)	Trace	Nil
Metaboric acid radicle (BO_2)	Nil	Nil
Arsenic acid radicle (AsO_4)	Nil	Nil
Chlorine (Cl)	116.256	116.25
Bromine (Br)	Nil	Trace
Iodine (I)	Nil	Nil
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	2.62	1.375
Manganese (Mn)	Nil	Nil
Barium (Ba)		
Strontium (Sr)		3.95
Calcium (Ca)	80.412	80.15
Magnesium (Mg)	63.90	67.70
Potassium (K)	8.532	6.654
Sodium (Na)	150.46	150.44
Lithium (Li)	Nil	Nil
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)	45.5 cc. per liter	35.3 cc. per liter
Classification	([b])	([b])
Remarks	([c])	([d])

[a] Transparent with bluish tint; odor of hydrogen sulphide.

[b] Thermal, sodic, sulphated, muriated, alkaline-saline, sulphureted.

[c] Hydrogen sulphide, 0.16 cc. per liter; 305 bacteria per cc.; specific gravity at 4° C., 1.0015; water, 34°.5 C.

[d] Probably of the same origin as the North Spring. Hydrogen sulphide, 0.16 cc. per liter; specific gravity at 4° C., 1.0015; water, 34°.5 C.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
October, 1910. Cebu, Guadalupe, Carcar. Spring. (a)	October, 1910. Cebu, Bolocboloc, Barili. Spring. Colorless, slight hepatic odor and taste.	October, 1910. Cebu, Kanaga, Sibonga. North Spring. (a)	October, 1911. Cebu, Kanaga, Sibonga. South Spring. (a)
18.575	27.67	23.21	21.38.
21.036	41.60	22.21	27.97.
303.35	372.16	349.64	360.8.
Nil	Nil		
2.618	Trace	Nil	0.5722.
1.8124	Trace	Trace	Nil.
Nil	Trace	Trace	Trace.
Nil	Nil	Present	Present.
Nil	Nil	Nil	Nil.
27.093	17.364	25.123	30.29.
Nil	Nil	Nil	Nil.
Trace	Nil	Nil	Nil.
0.37	1.00	1.58	3.875.
Nil	Nil	Nil	Nil.
			2.33.
64.51	90.33	68.97	70.31.
26.72	34.67	42.38	36.93.
2.832	2.05	5.88	5.89.
29.122	22.05	28.89	30.37.
Nil	Nil	Nil	
4.9 cc. per liter	5.35 cc. per liter	3.4 cc. per liter	10.0 cc. per liter.
(e)	(g)	(e)	(e)
(f)	(h)	(i)	(j)

[e] Thermal, calcic, bicarbonated, alkaline, sulphureted.

[f] Hydrogen sulphide, 2.3 cc. per liter; 212 bacteria per cc.; specific gravity at 4° C., 1.000; air, 29° C.; water, 34°.2 C.

[g] Calcic, bicarbonated, alkaline, sulphureted, carbon-dioxiated.

[h] Hydrogen sulphide, 0.28 cc. per liter; specific gravity at 4° C., 1.0006; air, 28°.5 C.; water, 31°.1 C. Number of bacteria excessive due to the lack of protection; contaminated by bathers.

[i] Hydrogen sulphide, 0.68 cc. per liter; air, 27° C.; water, 33° C.

[j] Hydrogen sulphide, 0.965 cc. per liter; specific gravity at 4° C., 1.0009; air, 27° C.; water, 32°.5 C.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
Date	October, 1911	October, 1910
Locality	Cebu, Kambañgog, Toledo.	Cebu, Mainit, Oslob.
Source	Spring	Spring A
Physical properties	[a]	[d]
Reaction		
Total solids		
Silica (SiO_2)	21.8	35.8
Sulphuric acid radicle (SO_4)	183.73	29.47
Bicarbonic acid radicle (HCO_3)	268.4	387.946
Carbonic acid radicle (CO_3)		Nil
Nitric acid radicle (NO_3)	Trace	Nil
Nitrous acid radicle (NO_2)	0.0302	Trace
Phosphoric acid radicle (PO_4)	Trace	Nil
Metaboric acid radicle (BO_2)	Present	Nil
Arsenic acid radicle (AsO_4)	Trace	Nil
Chlorine (Cl)	125.122	64.532
Bromine (Br)	Nil	Nil
Iodine (I)	Nil	Trace
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	2.75	1.125
Manganese (Mn)	Nil	Nil
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	60.437	58.9
Magnesium (Mg)	20.617	40.51
Potassium (K)	3.934	5.98
Sodium (Na)	182.45	64.85
Lithium (Li)	Nil	Nil
Ammonium (NH_4)		0.8182
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)	69.02 cc. per liter	5.5 cc. per liter
Classification	[b]	[e]
Remarks	[c]	[f]

[a] Continuous bubbling of sulphureted hydrogen and carbon dioxide.
[b] Thermal, sodic, alkaline-saline, sulphureted.
[c] Hydrogen sulphide, 20.56 cc. per liter; specific gravity at 4° C., 1.0009.
[d] Clear, transparent, opaline, gaseous bubbling; odor of sulphur dioxide.
[e] Thermal, sodic, bicarbonated, alkaline, sulphureted.
[f] Hydrogen sulphide, 4.1 cc. per liter; temperature of water, 35° C.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
		16301.	78438.
October, 1910	October, 1910	March, 1905	July, 1910.
Cebu, Mainit, Oslob	Cebu, Mainit, Oslob	Iloilo, Iloilo	Iloilo, Guimaras Island.
Spring B	Spring C	Well 70 meters deep	Spring.
([g])	([g])		
		Alkaline	
		2,348.0	250.4.
32.17	39.92	49.8	6.7.
28.75	24.071		4.3.
338.96	342.20		341.6.
Nil	Nil		Nil.
Trace	3.556		4.1.
0.5435	Trace		Trace.
Nil	Nil		Nil.
Nil	Nil		Nil.
Nil	Nil		Nil.
67.241	28.694	860.0	8.823.
Nil	Nil		Nil.
Trace	Nil		Nil.
		2.24	
1.37	1.00		
	Nil		Trace.
50.56	60.01	144.3	69.2.
40.06	50.27	83.4	3.8.
5.84	3.98		Trace.
64.81	27.00	600.6	5.0.
Nil	Nil		
10.5 cc. per liter	8.18 cc. per liter		
([e])	([i])		
([h])	([j])		

[g] Clear, transparent, opaline, gaseous bubbling; odor of sulphureted hydrogen.

[h] Hydrogen sulphide, 4.3 cc. per liter; 562 bacteria per cc.; specific gravity at 4° C., 1.0006; temperature of water, 35°.8 C.

[i] Calcic, magnesic, bicarbonated, alkaline, sulphureted.

[j] Hydrogen sulphide, 0.22 cc. per liter; 3,250 bacteria per cc.; specific gravity at 4° C., 1.0006; temperature of water, 29°.9 C. Number of bacteria excessive due to the lack of protection; people bathe inside the basin.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	97669.	102169.
Date	March, 1912	June, 1912
Locality		
Source	Imported	Imported
Physical properties	Golden yellow	
Reaction	Alkaline	
Total solids		
Silica (SiO_2)	44.0	67.3
Sulphuric acid radicle (SO_4)	15,888.0	Nil
Bicarbonic acid radicle (HCO_3)		1,475.8
Carbonic acid radicle (CO_3)		
Nitric acid radicle (NO_3)	1,919.8	
Nitrous acid radicle (NO_2)	Trace	
Phosphoric acid radicle (PO_4)	Nil	
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	2,058.8	94.1
Bromine (Br)		
Iodine (I)		
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	Slight	1.3
Manganese (Mn)	Nil	
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	983.2	77.2
Magnesium (Mg)	3,976.8	16.2
Potassium (K)	2,189.6	42.7
Sodium (Na)	1,483.2	471.5
Lithium (Li)	Slight	0.51
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		175 cc. per liter
Classification		
Remarks	([a])	([b])

[a] Labeled "Veronica Spring Water," from Santa Barbara, California.
[b] Mineral water labeled "Monsaris."

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
104468.	77156.	56358.	67958.
July, 1912	February, 1910	February, 1908	May, 1909.
	Laguna, Mabitac	Laguna, Mabitac	Laguna, Santa Rosa.
Imported	"Galas" Spring	"Galas" Spring	Stream.
	Alkaline	Alkaline	Alkaline.
692.2	880.4		410.0.
20.1	93.0	93.0	87.4.
Little	22.25	22.25	2.36.
146.01	318.89	318.89	367.599.
	Nil		
	Nil	Nil	Nil.
	Nil	Nil	Nil.
Trace	Nil	Nil	Nil.
	Trace	Trace	
	Nil		
294.1	355.6	355.6	
	Nil	Nil	
	Nil	Nil	
3.6	1.8	1.8	
1.5	0.333	0.333	
	Nil	Nil	
	Nil	Nil	
36.1	81.43	81.43	65.76.
2.8	32.97	32.97	16.3.
24.6	19.13	19.13	11.85.
94.5	207.6	207.06	44.89.
	Nil	Nil	
	0.422	0.422	
5.9753 grams per liter or 679 cc. per bottle of 225 cc.			
			(d)
(c)			

c Labeled "Dacapo" mineral water, Shanghai, China.

d Calcic, bicarbonated, alkaline.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	117796.	15434.
Date	December, 1913	February, 1905
Locality	Leyte, San Isidro	Manila, Singalong farm
Source	Hermosa Spring	Artesian well
Physical properties	Normal	
Reaction	Neutral	Slightly alkaline
Total solids	435.6	896.0
Silica (SiO_2)	21.7	Trace
Sulphuric acid radicle (SO_4)	11.2	165.0
Bicarbonic acid radicle (HCO_3)	386.0	
Carbonic acid radicle (CO_3)		
Nitric acid radicle (NO_3)	Little	
Nitrous acid radicle (NO_2)	Nil	
Phosphoric acid radicle (PO_4)	Nil	
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	45.81	194.0
Bromine (Br)		
Iodine (I)		
Iron (Fe)		Trace
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	Trace	
Manganese (Mn)		
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	94.4	12.8
Magnesium (Mg)	14.0	Trace
Potassium (K)	2.8	
Sodium (Na)	52.9	
Lithium (Li)	Nil	
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification	([a])	
Remarks		

[a] Calcic, bicarbonated, alkaline.

springs and other sources as noted—**Continued.**

parts per million.]

Laboratory No.			
31228.	51255.	118570.	116154.
June, 1906	February, 1908	May, 1914	September, 1913.
Manila	Laguna, Los Baños	Mindoro, Puerta Galera.	Misamis, Camiguin.
Tap water		Hot springs	Spring Coot, Catar.
	"Isuan"		Normal.
	Alkaline	Slightly alkaline	
215.4			348.4.
44.7	161.4	79.7	109.7.
	26.99	578.9	Trace.
	191.54	976.0	270.2.
		38.1	Nil.
	1.195		Trace.
	Trace		Trace.
			1.04.
	Trace		
	Nil		
3.9	367.5	518.0	4.41.
	Nil		
	Nil		
4.7			
	1.25	Nil	1.7.
	Trace		
	Nil		
	Nil		
16.4	90.35	169.7	51.1.
5.4	19.30	217.6	15.8.
2.3	30.8	355.1	6.9.
8.0	198.2	2,944.7	22.2.
	0.24		
	0.023		
	42.83		
			431.
			([d])
Tap water	([b])	([c])	([e])

[b] Thermal, sodic, calcic, bicarbonated, alkaline-saline, siliceous.
[c] Odor of hydrogen sulphide; contains organic matter.
[d] Calcic, bicarbonated, alkaline, sulphureted, carbon-dioxated.
[e] Hydrogen sulphide, 0.48 cc. per liter. Gases determined in laboratory; probably low.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	1085.	88870.
Date	March, 1903	August, 1911
Locality	Nueva Vizcaya, Dopol	Nueva Vizcaya, Salinas
Source	Saline spring	Saline spring
Physical properties		
Reaction	Alkaline	Neutral
Total solids	40,112	
Silica (SiO_2)	108.0	83.6
Sulphuric acid radicle (SO_4)		1,326.6
Bicarbonic acid radicle (HCO_3)		1,573.8
Carbonic acid radicle (CO_3)		Nil
Nitric acid radicle (NO_3)		
Nitrous acid radicle (NO_2)		
Phosphoric acid radicle (PO_4)		Slight
Metaboric acid radicle (BO_2)		Present
Arsenic acid radicle (AsO_4)		Nil
Chlorine (Cl)	22,167	21.01
Bromine (Br)		Present
Iodine (I)		Slight
Iron (Fe)		
Aluminium (Al)		
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)		Slight
Manganese (Mn)		Nil
Barium (Ba)		Nil
Strontium (Sr)		48
Calcium (Ca)	278.46	0.5754
Magnesium (Mg)	136.88	0.1363
Potassium (K)		182.6
Sodium (Na)		13.627
Lithium (Li)		Nil
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification		
Remarks		Salty taste

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
88870.	115260.	113846.	117015.
August, 1911	November, 1913	July, 1913	September, 1913.
Nueva Vizcaya, Salinas.	Occidental Negros, Buenavista.	Oriental Negros, Guijulñgan.	Oriental Negros, Masaplud.
Saline spring	Spring	Hot spring	Spring.
		Slight sediment, turbid.	Turbid.
Neutral		Alkaline	Acid.
	339.2	594.8	1,586.0.
108.6	9.2	30.0	242.0.
1,272.4	6.1	25.5	869.5.
1,647		326.9	Nil.
Nil	382.4	Nil	Nil.
	Nil	Little	Nil.
	1.1	Little	Nil.
Slight	Nil	Nil	Little.
Present	Trace		
Nil	Nil		
19,770	8.9	144.8	400.5.
Present	Nil		
Present	Nil		
			124.5 (Al_2O_3).
Slight	Trace	3.2	Trace.
Nil			
Nil	Nil		
41	Nil		
638.3	59.7	68.05	96.5.
124	4.1	26.9	31.9.
194.7	Little	Little	Little.
12,796	9.6	90.7	98.5.
Trace	Nil	Nil	Nil.
		(a)	(b)
Salty taste			

[a] Thermal, sodic, bicarbonated, saline.
[b] Aluminic, sulphated, acid.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.	
	113345.	13627.
Date	July, 1913	October, 1904
Locality	Oriental Negros, Polimpinon.	Palawan, Culion
Source	Hot spring	Spring
Physical properties	Turbid	
Reaction	Alkaline	
Total solids	6,025.2	
Silica (SiO_2)	184.0	Trace
Sulphuric acid radicle (SO_4)	99.6	2,505
Bicarbonic acid radicle (HCO_3)	158.5	
Carbonic acid radicle (CO_3)	Nil	
Nitric acid radicle (NO_3)	Nil	
Nitrous acid radicle (NO_2)	Nil	
Phosphoric acid radicle (PO_4)		
Metaboric acid radicle (BO_2)		
Arsenic acid radicle (AsO_4)		
Chlorine (Cl)	2,985.2	18,615
Bromine (Br)		
Iodine (I)		
Iron (Fe)		
Aluminium (Al)		Trace
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	2.8	
Manganese (Mn)		
Barium (Ba)		
Strontium (Sr)		
Calcium (Ca)	183.56	736.2
Magnesium (Mg)	50.7	1,014.6
Potassium (K)	Little	
Sodium (Na)	1,862.7	10,603.2
Lithium (Li)	Little	
Ammonium (NH_4)		
Oxygen to form Fe_2O_3		
Free carbon dioxide (CO_2)		
Classification		
Remarks		([a])

[a] About the same composition as sea water.

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.			
58527.	86907.	114328.	3323.
June, 1908	June, 1911	August, 1913	June, 1903.
Pampanga, Santo Tomas.	Pampanga, Mexico	Pangasinan, Balungao.	Rizal, Mariquina.
Artesian well	Artesian well	Spring	From Mariquina River.
Alkaline			Neutral.
		26,230.0	179.8.
38.5	45.6	35.0	34.2.
19.742	8.84	712.2	9.84.
185.897		23.2	
		Nil	Small amount.
Nil	Trace	Nil	
Nil	Trace		
0.73	0.5617	Nil	
Little			
Nil			
7.878		14,841.5	10.8.
Nil			
Nil			
			1.4
			3.6.
4.0	2.25	Trace	
Nil		Trace	
Nil			
Nil			
13.05	27.16	5,130.8	29.8.
1.992	18.28	Little	3.2.
7.128	4.37	25.5	Trace.
68.862	60.10	4,210.3	
Nil			
0.5676			
([b])		([c])	

[b] Sodic, bicarbonated, alkaline, siliceous.
[c] Sodic, calcic, muriated, sulphated, saline.

TABLE VIII.—*Analyses of waters from mineral*

[Numbers give

	Laboratory No.
	75529.
Date	January, 1910
Locality	Rizal, near Tanay
Source	Spring
Physical properties	Good
Reaction	
Total solids	
Silica (SiO_2)	103.73
Sulphuric acid radicle (SO_4)	2.807
Bicarbonic acid radicle (HCO_3)	175.68
Carbonic acid radicle (CO_3)	
Nitric acid radicle (NO_3)	0.419
Nitrous acid radicle (NO_2)	Trace
Phosphoric acid radicle (PO_4)	1.209
Metaboric acid radicle (BO_2)	Nil
Arsenic acid radicle (AsO_4)	Nil
Chlorine (Cl)	2.32
Bromine (Br)	Nil
Iodine (I)	Nil
Iron (Fe)	Trace
Aluminium (Al)	Trace
Iron oxide (Fe_2O_3) and alumina (Al_2O_3)	
Manganese (Mn)	
Barium (Ba)	
Strontium (Sr)	
Calcium (Ca)	34.069
Magnesium (Mg)	10.646
Potassium (K)	3.49
Sodium (Na)	16.28
Lithium (Li)	
Ammonium (NH_4)	
Oxygen to form Fe_2O_3	
Free carbon dioxide (CO_2)	
Classification	
Remarks	

springs and other sources as noted—Continued.

parts per million.]

Laboratory No.		
108098.	115733.	77563.
October, 1912	August, 1913	May, 1910.
Sorsogon, Sorsogon	Tayabas, Gasang, Marinduque	Tayabas, Gasang, Marinduque.
Mine water	Spring	Hot springs.
		Brownish; suspended matter.
Alkaline		Neutral.
	1,180.0	1,178.4.
	71.6	88.15.
Slight	87.2	65.425.
	939.4	928.236.
	Nil	Nil.
	Nil	Nil.
	Nil	Nil.
	Trace	6.4661.
		Little.
		Trace.
16.8	110.5	
		Nil.
		Nil.
2.2		
	2.4	13.5.
Nil		1.98.
		Nil.
		Nil.
2.8	257.9	227.3.
	47.7	46.21.
	21.7	0.52.
	100.8	161.00.
	Trace	0.731.
	206.8	
([a])	([b]) ([c])	

[a] Calcic, bicarbonated.

[b] Calcic, bicarbonated, alkaline, sulphureted, carbon-dioxated.

[c] Hydrogen sulphide, 1.16 cc. per liter. Values for CO_2 and H_2S are probably low.

The need of a systematic water survey in the Philippine Islands is strikingly apparent. Attention has repeatedly been called to this need as shown by the following quotation from an annual report of the Director of the Bureau of Science:[62]

> Our knowledge of the quality and quantity of available Philippine water supplies is extremely limited. * * * the bacterial count of water has little significance after a sample has been drawn for an hour or two without being kept on ice, and sanitary and mineral analyses of water should be considered more in the nature of a series of experiments than as giving results from which one may make a direct interpretation of the potability or medicinal value of the water. All classes of water analyses simply assist us to judge the character of the water. Without an accurate knowledge of the normal constituents of the source, the conditions under which the sample was taken, and the other factors which influence it, it is impossible to pass judgment upon a water. An investigation and study of all medicinal and thermal springs in the Islands should be undertaken, and a reservation as a public domain of a suitable area surrounding those of value should be made. It seems to me that it is a duty the Government owes to future generations to provide an adequate water survey at the present time. When funds are available, an appropriation should be made to this Bureau for carrying on a careful survey of Philippine water supplies.

The standards laid down for water in the United States, especially in regard to chlorine and ammonia content, are not applicable to conditions in the Archipelago, and unless a special study of the subject of water supplies is carried on it will be many years before the routine work will have furnished enough data to warrant definite conclusions. There are also much-needed analytical results which can be secured only with a portable laboratory in connection with field work.

Even at the present time there are many valuable data in the possession of the Bureau of Science which should be much more useful to persons interested in the problem of water supply than has been the case. Thousands of pesos have been spent in drilling wells in the Islands in places where a study of available geologic and chemical data would have shown conclusively the impossibility of obtaining a suitable supply of water. A careful survey would prevent unwise expenditure in unknown barren districts.

By combining the geologic information with all available chemical and biological data concerning the water occurring in any one district, it should not be difficult to establish safe limiting values for the normal constituents of water to serve as a basis in determining its fitness for any particular purpose.

[62] Cox, *12th Annual Rep. P. I. Bur. Sci.* (1913), 107.

ILLUSTRATIONS

Fig. 1. Open well near municipal building, Taytay, Rizal Province.

Fig. 2. Outhouse in proximity to well, Taytay, Rizal Province.

PLATE I.

Fig. 1. Open well, Pasay.

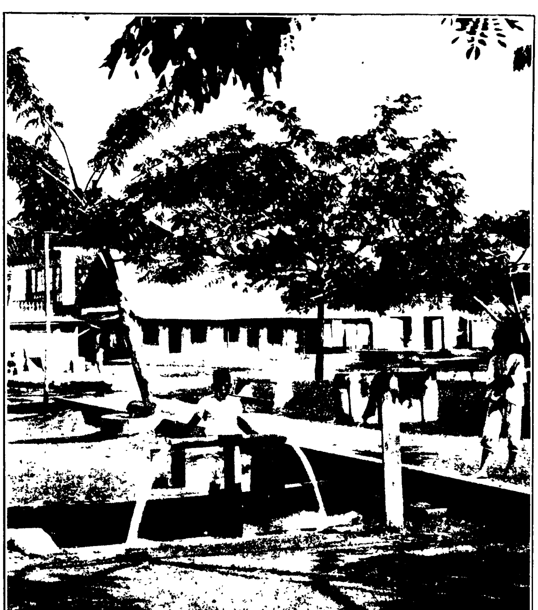

Fig. 2. Flowing well, Malolos, Bulacan.

Fig. 3. Flowing well, Malolos, Bulacan.

PLATE II.

Fig. 1. Water carriers at a public hydrant, Manila.

Fig. 2. Carrying water in a bamboo tube; a common provincial method.

Fig. 3. Typical venders of milk and native drinks which are frequently diluted with impure water.

PLATE III.

PLATE IV. SITE OF THE MANILA CITY WATER SUPPLY DAM AT MONTALBAN, LOOKING UPSTREAM TOWARD THE DAM.

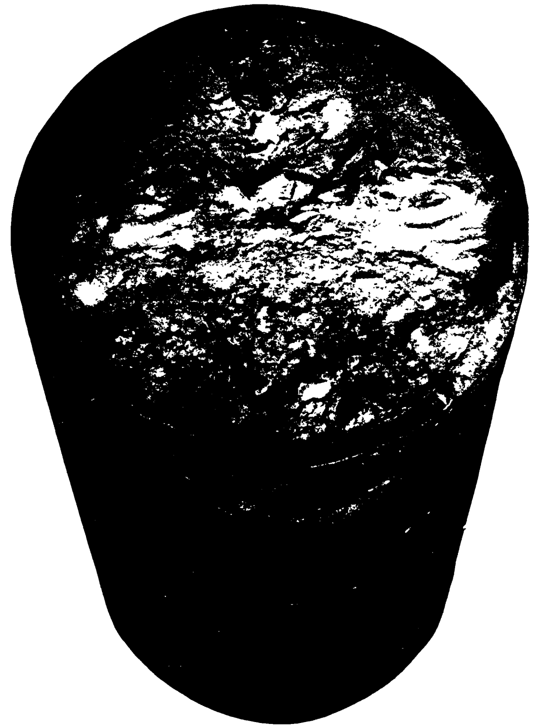

Fig. 1. Section of a boiler tube entirely closed with scale, taken from a neglected boiler in the provinces.

Fig. 2. Section of the same tube, showing an iron cleaning rod broken off in an attempt to remove the scale.

PLATE V.

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PHILIPPINE DIPTEROCARP FORESTS

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Thirteen plates, 12 text figures, and 1 map

CONTENTS

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INTRODUCTION

The fact that the dipterocarp forests are the most extensive and important forests of the Indo-Malayan region has been pointed out by a number of writers, but up to the present time little or no attempt has been made toward an understanding of the factors influencing their growth and development. A clear comprehension of these factors is important from an ecological point of view, and is absolutely necessary if the forests are to be handled according to rational silvicultural practice. The need of such data has led us, one a botanist and the other a forester, to undertake this study with the hope that it will result in a foundation which will help in the future understanding and management of these forests. Both of us have been in full coöperation in all parts of the work, although naturally some portions are more particularly the result of individual investigations. The results here presented are, therefore, in effect the conclusions of both.

We were particularly fortunate in having the assistance and criticism of Dr. F. W. Foxworthy, who has made an extended study of the trees of the Indo-Malayan region and especially of the dipterocarps; of Dr. E. B. Copeland, who is thoroughly acquainted with the vegetation of the Philippines; and the assistance of Mr. E. D. Merrill in the identification of specimens.

A list of all the species mentioned is given at the end of this article.

GENERAL DESCRIPTION OF DIPTEROCARP FORESTS

The dipterocarp forest is a tall, tropical lowland forest characteristic of the Indo-Malayan region, usually occupying the localities most favorable to tree growth. It receives its name from the fact that species of the family Dipterocarpaceae are the dominant trees. The forest may be composed almost wholly of one dipterocarp species, as in some of the forests of *Shorea robusta* of northern India and of *Dipterocarpus tuberculatus* of Burma.[2] In other cases two or more different species may predominate. In many forests the numerical proportion of dipterocarps may be small, but owing to their large size they may yet give a characteristic appearance to the vegetation and form a large proportion of the volume of timber. This condition

[2] Brandis, D., An enumeration of the Dipterocarpaceae based chiefly upon specimens preserved at the Royal Herbarium and Museum, Kew, and the British Museum; with remarks on the genera and species, *Journ. Linn. Soc. Bot.* (1895), 31, 1–148.

will be brought out in connection with the forest of Mount Maquiling. Dipterocarp forests may thus contain a relatively small number of dipterocarps, but the individuals are mostly large trees, and one of the chief characteristics of this family is the production of large stands by one or several species.

To quote from Brandis:

> The most striking peculiarity of this order is, that numerous species are gregarious, forming nearly pure forests of large extent in which one species has obtained the upper hand, to the exclusion almost of all others. In the tropical forests of Eastern Asia these species play the part which in Europe belongs to trees of Coniferae and Capuliferae * * *. The most remarkable of these gregarious species is the Sal tree, *Shorea robusta*, which forms pure or nearly pure forests of vast extent at the foot of the Himalaya, * * * and in the hills of Eastern Central India * * *. In a climate and on soil which suits it, this tree reigns supreme.

Although the dipterocarps form large stands, there are usually a number of other species associated with them. Whitford reports [3] 120 different species on 10,200 square meters in the Lamao forest of Bataan, P. I. Of these, 7 were dipterocarps. On a plot of 2,500 square meters on Mount Maquiling there were 92 different species, only 2 of which were dipterocarps. Many of the species growing with the dipterocarps are small, there being frequently 2 stories composed of different species growing under the first or dominant story. Besides these smaller trees, there are frequently also in the first story, larger species other than dipterocarps, some of which may reach the height of the tall dipterocarps. Kurz [4] describes the tallest story of the closed tropical forests of Pegu as being composed chiefly of deciduous Sterculiae, while along with these there are evergreen dipterocarps and trees of other families. Between this forest which can hardly be called dipterocarp and one in which the top story is composed almost exclusively of dipterocarps there must be many different types.

The number of large trees other than dipterocarps naturally varies inversely as the number of dipterocarps. The same is usually true also of the small understory trees, the reason being that as the dipterocarp layer becomes more highly developed less light passes through it.

Dipterocarp forests extend from northern India through Ceylon, Burma, Indo-China, Malay Peninsula, and Sumatra to

[3] Whitford, H. N., The vegetation of the Lamao forest reserve, *This Journal* (1906), 1, 373.

[4] Kurz, S., Preliminary report on the forest and other vegetation of Pegu. C. B. Lewis, Baptist Mission Press, Calcutta (1875).

Java, Borneo, and the Philippines; and probably also to Celebes and New Guinea, as dipterocarps have been reported from these regions. These forests usually occur below elevations of 1,000 meters, and generally show the greatest development at low elevations. They generally occupy the regions best suited for tree growth. Dipterocarp forests usually give place to other types in dry regions, but the requirements of different dipterocarp forests as to moisture and temperature vary greatly. In the constantly humid forests of Sarawak, Borneo, dipterocarps are conspicuous, while in Bengal *Shorea robusta* occurs in localities where the dry season is so pronounced that fires cause considerable damage to the forests.[5] These two regions also illustrate the differences in temperature endured by dipterocarps, the forests of Sarawak having a continuous high temperature, while *Shorea robusta* in Palaman and Hagaribagh Districts of Bengal is repeatedly injured by frost.

DISTRIBUTION IN THE PHILIPPINES

According to Whitford,[6] the dipterocarp forests cover 75 per cent of the virgin forest area of the Philippines, or 77,700 square kilometers (30,000 square miles), and contain approximately 95 per cent of the standing timber. These forests occur on almost all types of topography, but usually grow best on well-watered plains or on the gentle lower slopes of the main mountain masses. On such sites the soil is usually a deep loamy clay of volcanic origin, and as we pass from these situations to soils of a drier nature and of calcareous origin the dipterocarp species give way to a more open type usually dominated by such species as *Vitex parviflora* (molave). Both dipterocarp forests and the individual trees are best developed at comparatively low altitudes, and as higher elevations are reached the trees become smaller and the dipterocarps less numerous. At elevations of 800 meters or less this type gives way to one in which miscellaneous trees—*Quercus* and other genera—are more prominent. Dipterocarp forests may extend practically to the sea, where situations favorable to them occur, but they do not grow on sandy beaches or muddy flats. However, the type is not usually found within 3 or 4 kilometers of

[5] McIntire, A. L., Notes on sal in Bengal, *Forest Pamphlet, Calcutta* (1909), No. 5.

[6] Whitford, H. N., The forests of the Philippines, *Bull. P. I. Bur. Forestry* (1911), No. 10.

the coast in most regions, because where situations suitable for it are found near the beach the original forest has been for the most part cleared away and the land put under cultivation.

The accompanying map, which is a modification of Whitford's,[7] shows the distribution of forest areas throughout the Philippine Islands. The pine forest shown on the map in double hatch is a high mountain type and need not interest us here. No distinction is made in the map between large areas of commercial forest which are chiefly dipterocarp, small areas of high mountain forest, and forests of the drier sites that occur scattered through the larger forest areas. For the purposes of this paper the forest area may be considered for the most part dipterocarp. Large portions of the forests have been only partially explored, but will probably prove to be of the same general character as those in better-known parts of the Islands.

The distribution of the forests as shown in this map is in part due to climatic differences and in part to the influence of man aided by climatic conditions. Temperature plays little part in this distribution, as temperature in the Archipelago is regulated by altitude rather than by latitude.[8] Moisture conditions seem to be the determining factor. In general, the climate of the Philippine Islands, in regard to rainfall, may be classified as a monsoon climate; that is, rains depend upon rain-bearing winds which shift their direction twice a year. This statement is essentially correct for the entire western side of the Archipelago, but cannot be taken literally for the eastern portion. The rainfall of the Islands can be divided into two general classes. The first class may be distinguished as a seasonal rainfall, the climate being marked by very distinct wet and dry seasons. This climate is found in the western half of the Archipelago. In the eastern part of the Islands rainfall is distributed throughout all the months of the year, and there are therefore no pronounced wet and dry seasons. The explanation of this difference between the eastern and western coasts of the Islands is that the northeastern monsoon, striking the Islands on the eastern coast, deposits a large part of its moisture before passing over the mountain masses and then continues over the western half of the Islands as a drying wind. The southwestern monsoon, on the other hand, is not

[7] *Bull. P. I. Bur. Forestry* (1911), No. 10.

[8] Cox, A. J., Philippine soils and some of the factors which influence them, *This Journal, Sec. A* (1911), 6, 279–330.

nearly so strong a wind, and although it brings rains on the western side of the Archipelago a large part of the rains which come at this season of the year is the result of cyclonic disturbances (typhoons) which cause the deposition of rain on both coasts.

This difference in the character of rainfall between the eastern and western halves of the Archipelago is pronounced on Luzon, where there are large mountain masses running north and south. Forest areas are very extensive on the eastern side, where there is a nonseasonal climate. The same relation between forests and rainfall is also evident to some extent in the southern islands, particularly so in Mindoro, which like Luzon has a high central mountain range running north and south and a rather nonseasonal rainfall on the eastern side which is also heavily forested. Cebu, on the other hand, which lies farther east than Mindoro, is a relatively low island, and being sheltered on its eastern side by Leyte and Samar has a very distinct seasonal climate and is almost without forest.

This relation between the distribution of forests and rainfall is due to the seasonal character and not to the total amount of rainfall. The average rainfall as taken at the weather stations for the western, seasonal or monsoon, climate is 2,327.3 millimeters per year; for the eastern or nonseasonal climate, 2,273.7 millimeters.[9] Moreover, the total range of rainfall in each climate is considerable, varying from 1,188.8 millimeters to 3,954.4 millimeters in the region of monsoon rainfall and from 905 millimeters to 3,859.2 millimeters in the region of nonseasonal rainfall. Thus, it is evident that if any relation between forest distribution and rainfall is to be established it must depend upon the seasonal character rather than upon the total amount of rainfall. What has been said in regard to rainfall will apply over large areas, but the local configuration of mountain masses will, of course, affect these conditions very considerably.

It is very probable that, with the exception of certain limited very dry regions, all of the Archipelago was originally covered with forest, the greater part of which was dipterocarp in character. The extensive grass areas and second-growth forests which now occupy a large portion of the Islands are undoubtedly due in large part to the influence of man. In this connection it may be interesting to refer to the following table (Table I) from Whitford:[10]

[9] Cox, loc. cit.

[10] *Bull. P. I. Bur. Forestry* (1911), No. 10.

TABLE I.—*Areas covered by different classes of vegetation in the Philippine Islands.*

Class of vegetation.	Area.	
	Sq. miles.	*Per cent.*
Virgin forests	40,000	33⅓
Second-growth forests	20,000	16⅔
Grasslands	48,000	40
Cultivated lands	12,000	10
Total	120,000	100

As will be seen here, the grasslands are more extensive than virgin forests, while the extent of cultivated lands is only one-fourth as great as that of the grasslands. There can be no doubt that these grass areas are a result of cultivation. The cogon grass (*Imperata exaltata*) readily invades cultivated areas and often leads to their abandonment, or the land, after a lapse of cultivation, becomes overgrown with this grass, which effectually prevents further cultivation. By reference to map 1 it will be seen that the nonforested areas largely overgrown with grass are most abundant in the region of the pronounced dry season. The reason for this is that the grass becomes very inflammable during the dry season and is regularly burned. This results in the death of nearly all tree seedlings and in the extension of the grass areas. These fires do little or no damage to the grass on account of its large underground rhizomes. In the region of nonseasonal rainfall the grass areas more rarely become dry enough to burn readily. Consequently, forest species can become established in areas abandoned after cultivation and the forest is able to maintain itself. Thus, it seems evident that the present distribution of forests in the Philippines is largely due to the combined effect of the action of man and the influence of climate, human activity in destroying the forest being aided in the western half of the Archipelago by climate and retarded in the eastern half.

IMPORTANCE OF DIPTEROCARP FORESTS

The importance of the dipterocarp family as the source of the chief timber supply of the Philippine Islands was first clearly shown by Whitford.[11] Whitford estimates that the dipterocarp forests contain 95 per cent of the standing timber in the Philippines and that 75 per cent of this timber is dipterocarp. As stated in the above paper, 144 out of a total of 200

[11] Forests of the Philippines, *Bull. P. I. Bur. Forestry* (1911), No. 10.

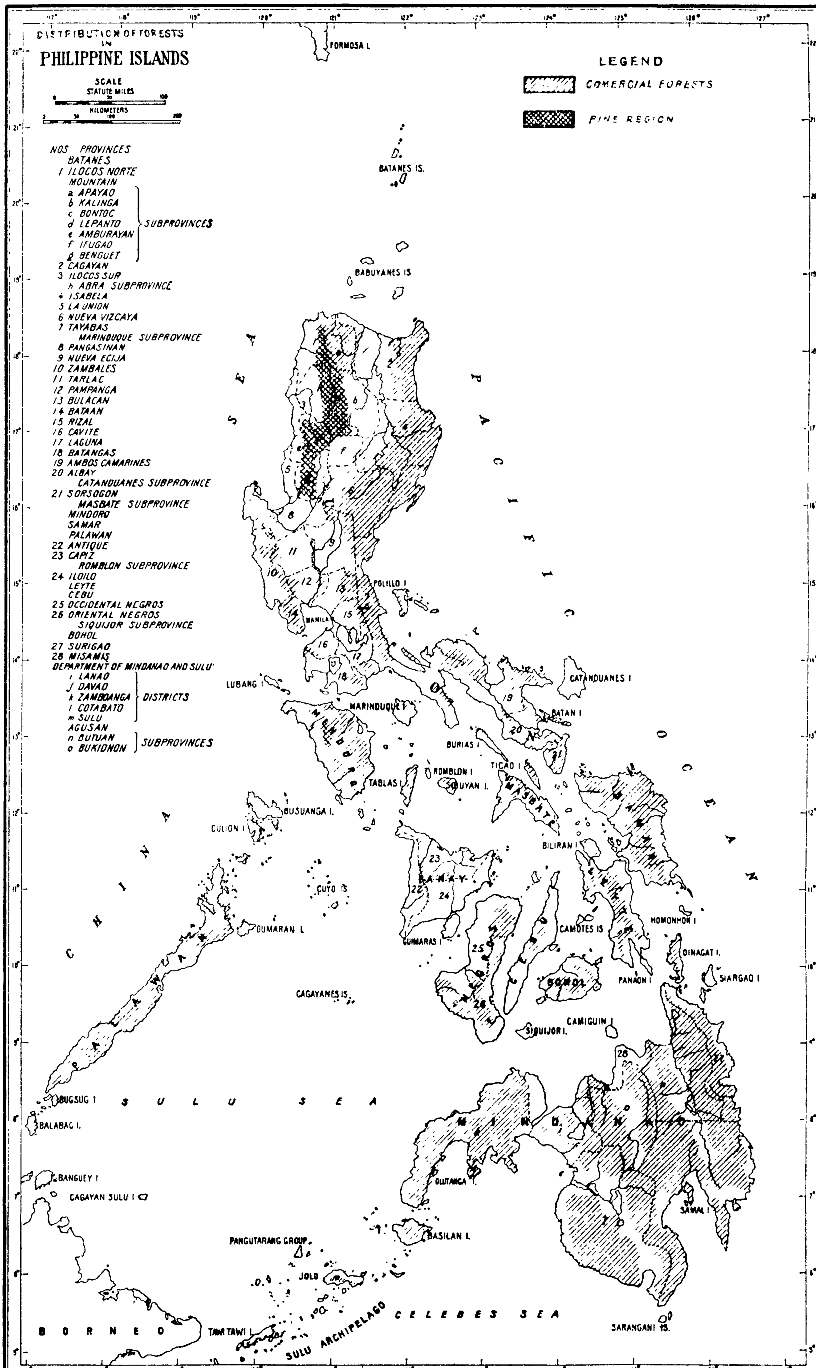
billion board feet of standing timber in the Philippines is estimated to be dipterocarp. The large size of the individual trees, the density of the stand, and the readiness with which the market receives the timber for construction and finishing work of all kinds make the forest an extremely important one to the logger; and capital has already been invested in the commercial development of this forest to a very considerable extent. Other timber of greater value for cabinetwork and interior finish is found in the Philippines, as throughout the tropics, but not in sufficiently heavy stands to warrant the investment of large amounts of capital. Certain grades of dipterocarp timber are, however, eminently suited to take the place of such woods as walnut and mahogany, while other grades furnish excellent construction timber; these two uses make the exploitation of the forests on a large scale a certainty. If the destruction that has attended the exploitation of valuable forests in other countries is not to be repeated here it will be necessary to obtain a thorough understanding of their growth and reproduction, from which can be deduced a rational system of silvicultural management.

The importance of the sal forest, a dipterocarp type of India and Burma, has long been recognized by Indian foresters who have prepared elaborate plans for its management. In general, however, the importance of the dipterocarp type has not been recognized, but from data at hand it seems probable that it is just as important throughout the Indo-Malayan region as a whole as in the Philippines. The impression has prevailed that the tropics furnish only very heavy hardwoods and cannot be counted on for soft and medium-hard construction timbers, which constitute the bulk of these used throughout the world. Thus Fernow [12] says:

> Most of the woods of the tropics are very hard, fit primarily for ornamental use and hence less necessary. Possibly a change in the methods of the use of wood may also change the relative economic values, but at present the vast forests of the tropical countries are of relatively little importance in the discussion of wood supply for the world.

It seems evident that this statement does not apply to the Indo-Malayan region and certainly not to the Philippines nor to the sal forests of India and Burma. The dipterocarps, in general, are soft and medium-hard woods, and without doubt occur in sufficient quantities partially to meet the world's demand. That they are not more generally used for construction purposes

[12] Fernow, B. E., A brief history of forestry. University Press, Toronto; Forestry Quarterly, Cambridge, Mass. (1911), 4.



MAP 1. Distribution of forests in the Philippines.

outside of the region in which they occur is naturally due to the fact that only the better grades have been exported, and these the world markets have accepted as finishing lumber. Furthermore, the primitive methods of lumbering, which until recent date have been the only ones in use in the tropics, have made lumbering expensive and the handling of large trees impossible. Under these conditions, the only woods which could be exported with profit have been the very hard ones which are in constant demand for ornamental purposes and for which very high prices are paid. With the introduction of modern logging machinery, lumbering in the Philippines is becoming constantly cheaper, the supply of construction timber is exceeding the local demand, and exportation of various classes of lumber has begun.

Comparatively little is known of the class of timber existing in the extensive forests of tropical Africa and South America, but judging from descriptions of forests in both of these regions the stands are dense and are composed of large trees. Pechuel-Lösche [13] in his description of the west African rain forest says:

> There is rather a rich repetition of certain forms developed into giants which invest it with an imposing uniformity.

Again, Stanley [14] describes the forests of the great Congo region as composed largely of great buttressed trees with clean boles. Schimper [15] in speaking of the forests of tropical America says:

> The tropical virgin forest of America has very properly acquired the highest reputation. The ordinary descriptions of tropical virgin forests chiefly refer to it * * *. I found it, in many ways, far more majestic than in Java, owing to the larger dimensions of the trees, * * *.

It seems not unlikely that further exploration of these regions will develop the fact that they are capable of supplying a large proportion of the construction timber of the world.

COMPOSITION AND ARRANGEMENT OF PHILIPPINE DIPTEROCARP FORESTS

Most of the descriptions of tropical forests have been written by naturalists who were looking for new and curious forms of plants. Their descriptions and pictures have, therefore, led to the popular impression that tropical forests are composed largely

[13] Pechuel-Lösche, E., Die Loang-Expedition. Abth. III, Hälfte 1. Leipzig (1812). See Schimper, Plant geography. Oxford (1903).

[14] Stanley, H. M., In darkest Africa. C. Scribner's Sons, New York (1913).

[15] Schimper, A. F. W., Plant geography. Univ. Cambridge Press, Oxford (1903).

of bizarre plants and that their appearance is almost entirely different from that of temperate ones. The low, mossy type of high mountains is certainly very different from anything seen in temperate countries. The tall dipterocarp type of forest, however, presents an appearance strikingly similar to a deciduous forest of the temperate zones; it differs from the latter largely in having the trees arranged in stories, with an accompanying greater density of foliage, and especially in containing a much larger number of different species (Plate I, fig. 1). In the best-developed dipterocarp forests the top story forms a very even canopy, reaches to a height of about 65 meters or more, and is composed almost entirely of dipterocarps (Plate V). The trees frequently have a diameter of 1.5 meters and sometimes 2.5 meters or more (Plate VII). In more poorly developed types this story is lower and may contain more trees of other species than of dipterocarps, while the canopy is frequently very irregular, as the dipterocarps are still the predominant large trees and tend to tower over the other species.

Under the top story there are two other stories, each composed of distinct trees, and a ground covering of small bushes or herbs (Plate VI, fig. 2). The presence of these three stories of different trees is not evident on casual observation, for the composition of all of the stories is very complex and few of the trees present any striking peculiarities, while smaller trees of a higher story always occur in a lower story and between the different stories. The development of the lower layers is usually in inverse ratio to that of the top story, the reason being that the better the top story is developed the less light passes through to the lower stories (compare Plate I, fig. 2, and Plate II, fig. 1). The middle story is composed of fair-sized trees which spread their leaves under the branches of those of the top story. The trees of the third or lowest story are small, about 10 to 12 meters high, and have a relatively small amount of foliage (Plate VI, fig. 2). Tree palms probably occur in all of the dipterocarp forests of the Philippines, and may exceptionally form a conspicuous part of the vegetation in small pockets (Plate II, fig. 2). In the best types they are usually relatively inconsiderable parts of the vegetation.

Climbing palms (rattans) (Plate VI, fig. 2) are always present in large numbers, although they are much more prominent in the poorer than in the best types of forest. The rattan plant forms a rosette when young, and maintains this form until the spiny, pinnate leaves are from 2 to 3 meters long. After this it sends out a climbing stem with long internodes, and may

attain a length of more than 100 meters. Rattans in the rosette stage usually form the most conspicuous part of the ground covering, and difficulty in penetrating the undergrowth is usually due to the spines of the rattan rather than to the density of the vegetation.

The composition of the ground covering other than the rattans varies greatly in different situations. On ridges of the lower slopes of mountains in regions with a pronounced dry season it consists almost altogether of small woody shrubs. In ravines, near streams, ferns are numerous, while miscellaneous herbaceous plants occur in considerable numbers. Near the upper edge of the dipterocarp forest and in regions without a pronounced dry season, ferns and herbaceous plants are often present in large numbers even on the ridges.

Large vines are a characteristic feature of the dipterocarp forest (Plate I, fig. 1), and in poorer-developed types of forests they may be prominent enough to influence the appearance of the vegetation markedly, while in the best types they are much less noticeable. In the poorer and particularly in cut-over types climbing bamboo is frequently well developed. The greater development of vines in the poorer types is connected with the fact that more light comes through the canopy of the top story than in the best types.

Epiphytes, which are very prominent in the mossy forest, are in the dipterocarp type chiefly restricted to the larger branches of the tall trees where they form regular aërial gardens. The chief constituents of these are ferns—particularly humus-gathering ones, such as species of *Drynaria*—xerophytic orchids, and species of *Hoya*. These are frequently so completely hidden by the foliage beneath them as to be invisible from the ground. Epiphytes on the trunks of the trees are rather scarce and, with the exception of the bird's-nest fern (*Asplenium nidus*), are usually inconspicuous. The bird's-nest fern, on the other hand, with its fronds a meter or more in length is the most striking epiphyte in the forest. It does best in somewhat moist localities, and is almost entirely absent from dry ridges.

We have seen that the dominant trees of the forest are dipterocarps and that as these increase in number and size the other constituents of the forest become less prominent. This is probably connected with the fact that as the dipterocarps become better developed they shut out more light from the lower stories. In the best forests there are sometimes small patches where the dipterocarps cast such a dense shade that there is practically nothing growing on the ground under them. However, such

places are rare, as both the understories and ground covering are usually very dense, the average undergrowth in a good forest being always much more abundant than in a well-developed deciduous forest of the temperate zone. The forest is, however, far from being an impenetrable jungle. One can pass through it readily if he carries a long knife to cut the spiny leaves of the rattan, while even this is unnecessary in the best types. However, the edges of even the best types of forest are very dense (Plate IV, fig. 1).

Comparing the appearance of the dipterocarp forest with a deciduous forest of the temperate zones, the chief difference lies in the greater density of the dipterocarp type. This difference in density includes foliage, undergrowth, and the number of trees and vines. Next to density comes the presence of palms, particularly of the rattans, which form such a conspicuous element in the undergrowth. Besides this, the peculiarities of certain trees should be noted. These are buttresses, cauliflory, and the presence of strangling figs. A considerable proportion of the tall trees have tremendous planklike buttresses (Plate VI, fig. 1), which in extreme cases extend several meters from the tree and probably help to support it. The strangling figs, species of *Ficus,* present a most peculiar appearance (Plate III, fig. 1). Starting as epiphytes in the tops of the trees, they send down roots which become connected with the ground (Plate III). Branches from these roots grow around the tree and coalesce either with each other or with a main root, until the trunk of the tree on which the fig started, usually, becomes inclosed by a network. As this grows it interferes with the growth of the trunk, the fig leaves shade the tree, and roots of the fig interfere with those of the tree. This combination usually results in the death of the tree on which the fig is growing. The meshlike support of the fig continues to grow until it may finally assume the appearance of a solid trunk. These strangling figs frequently occur on the largest trees, but are much less numerous in the best forests than in the poorer types. Cauliflory occurs in a number of species, particularly of the genus *Ficus.* However, neither strangling figs nor cauliflorous trees are present in the best types in sufficient numbers to influence the general appearance of the vegetation.

If we were to sum up the impression which one gets in passing through a dipterocarp forest it would be something like this: A tall, dense forest is seen in which large trees and small ones are crowded together until their leaves very fully occupy all of the available space, while the ground is covered with a

dense undergrowth consisting largely of feathery rattans, some of them reaching up among the trees. Scattered here and there are tall palms, while now and then the eye is caught by a large tree with gigantic buttresses, the bizarre form of a strangling fig, a tree trunk covered with fruit, or the long leaves of the epiphitic bird's-nest fern.

There are, of course, in the forest many curious plants of great interest to the botanist, but these plants are frequently inconspicuous or their peculiar features are such as would only attract a naturalist. They do not influence the general character of the forest, and might readily be overlooked by the casual observer.

We have discussed the dipterocarp forest as though it were a single type. This is true of the general features such as have been described. The systematic composition of different forests, however, varies considerably. Thus, in the forest on the northern and eastern slopes of Mount Maquiling, *Parashorea plicata* (bagtican-lauan) is the only dipterocarp present in sufficient numbers to give character to the vegetation. On the eastern slopes of Mount Mariveles, at an elevation of about 500 meters, *Shorea polysperma* (tanguile) occurs in much greater numbers than any other dipterocarp. The dominant story of the forest of northern Negros on the banks of Himugan River is composed chiefly of four dipterocarps, *Shorea negrosensis* (red lauan), *Shorea eximia* (almon-lauan), *Dipterocarpus grandiflorus* (apitong), and *Shorea polysperma* (tanguile). The differences, here mentioned, are much greater than those between some other forests, as the forests grade into each other. There are, however, almost as many types as there are forests, and it is even difficult to divide them into general groups. For the purposes of this paper it seems best to regard such dipterocarp forests as are discussed as being of one type with many variations.

DESCRIPTION OF SELECTED AREAS

The dipterocarp forest as it occurs throughout the Indo-Malayan region and the Philippines has already been discussed, and now certain selected forest areas in the Philippines will be taken up and discussed more in detail. The forests described below have been chosen not only because they are typical of a large portion of the dipterocarp forests of the Philippines, but also because growth and other silvicultural data which will be used later in the discussion of the management of the dipterocarp type have been obtained in these regions. Also, these forests are typical of different forms of the dipterocarp type,

and each forest presents a somewhat individual problem in its management.

THE FOREST OF NORTHERN NEGROS

The northern end of Negros is characterized by broad gently sloping ridges which extend from a broad coastal plain inland to a volcanic cone rising to an elevation of about 1,400 meters. The climate of the region is nonseasonal in character at all points above 100 meters in elevation. The soil is a deep, fertile, well-drained clayey loam of volcanic origin. The forest extends on the northern and eastern slopes to within 6 kilometers of the coast, where the altitude is from 30 to 50 meters. It is dipterocarp in character up to elevations of 700 meters and over, where it grades into mountain-top forms, but it reaches its best developement on the lower broad gentle slopes up to elevations of 500 meters.

On the broad lower slopes the forest is typical of the best-developed forests of the Islands (Plate V). From the standpoint of yield and simplicity of composition, the forest is unsurpassed. The dominant trees, numerically and commercially, are only six, and all are dipterocarps. They are *Shorea negrosensis* (red lauan), *Shorea polysperma* (tanguile), *Shorea eximia* (almon-lauan), *Pentacme contorta* (white lauan) *Parashorea plicata* (bagtican-lauan), and *Dipterocarpus* spp. (apitong). These trees are all of large size, attaining an average diameter of 70 centimeters and a height of 50 meters. Individual trees attain diameters of over 250 centimeters and heights of over 65 meters, and over large areas the average diameter of the 6 species may run as high as 100 centimeters (Plate IV, fig. 1, and Plate V). Owing to the fact that the top story is so highly developed, the under stories are less prominent than in the average dipterocarp forests. This forest is, therefore, not as typically three storied as are most forests in the Islands. An analysis of the stand shows a striking lack of intermediate-sized trees of the predominant species. The understory is for the most part made up of a great number of minor species which are too small and too varied in quality to be of importance commercially. In other words, the forest approaches an even-aged stand of overmature dipterocarps with a scanty understory of mixed pole-sized dipterocarps and miscellaneous species. This fact is illustrated by Table II compiled from data given by Everett and Whitford [16] in their working plan for this area.

[16] Everett, H. D., and Whitford, H. N., A preliminary working plan for the public forest tract of the Insular Lumber Company, Occidental Negros, P. I., *Bull. P. I. Bur. Forestry* (1906), No. 5.

From Table II it may be seen that although, exclusive of seedlings under 10 centimeters in diameter, there are nearly as many individuals of dipterocarps below 40 centimeters in diameter as there are above, nevertheless, the great bulk of the forest in regard to volume is distributed among the larger trees. Furthermore, the same fact holds true in regard to the distribution of the canopy. The main canopy of the forest is that of the standards and veterans, and this is an entirely closed canopy. The trees of as small diameters as 40 centimeters have their crowns overtopped by the crowns of the main overmature stand, and, as a consequence, these trees are poorly developed, slender poles with suppressed crowns. When

TABLE II.—*Stand table for forest of northern Negros.*

[Volumes are given in cubic meters.]

Diameter of tree above buttresses in centimeters.	*Dipterocarpus* sp. (apitong).		*Shorea eximia* (almon).		*Shorea polysperma* (tanguile).		*Shorea negrosensis* (mangachapuy, or red lauan).	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
15	8.47	0.34	8.58	0.34	2.51	0.10	3.18	0.18
25	9.61	2.40	8.25	2.06	3.86	0.96	4.48	1.12
35	5.38	3.23	4.59	2.74	2.32	1.39	2.32	1.34
40	3.22	3.86	1.98	2.97	1.35	1.73	1.61	2.24
45	3.29	5.13	1.96	4.31	1.28	2.06	1.22	2.18
50	2.30	4.69	1.54	4.02	1.10	2.21	1.30	2.91
55	1.83	4.76	1.26	4.10	0.75	1.89	1.17	3.24
60	1.88	6.02	1.17	4.65	0.95	2.99	1.04	3.54
65	1.63	6.65	1.00	4.70	1.06	4.05	1.15	4.69
70	1.11	5.50	0.81	4.45	0.66	3.05	1.04	5.05
75	1.10	6.60	0.75	4.82	0.59	3.10	0.99	5.66
80	0.64	4.61	0.93	6.89	0.55	3.54	1.08	7.24
85	0.60	5.12	0.88	7.39	0.60	4.46	0.91	7.05
90	0.51	5.11	0.46	4.39	0.46	3.94	0.69	6.15
95	0.25	2.90	0.33	3.54	0.31	3.01	0.78	7.96
100	0.14	1.86	0.51	5.66	0.40	4.39	0.71	8.24
105	0.31	4.71	0.64	8.73	0.27	3.33	1.10	14.40
110	0.13	2.31	0.42	6.43	0.16	2.20	0.97	14.34
115	0.037	0.77	0.38	6.51	0.13	1.98	0.71	11.01
120	0.054	1.25	0.40	7.66	0.16	2.68	0.91	16.67
125	0.054	1.46	0.11	2.34	0.16	2.92	0.68	13.77
130	0.037	1.05	0.11	2.60	0.18	3.60	0.59	13.13
135	0.018	0.56	0.16	4.18	0.091	1.99	0.53	12.88
140			0.16	4.60			0.69	18.22
145	0.018	0.65	0.091	0.69	0.054	1.41	0.25	6.12
150			0.091	0.70	0.037	1.05	0.29	8.95
155							0.13	4.30
160			0.018	0.15	0.018	0.60	0.24	8.40
165								
170			0.018	0.18			0.074	2.98
Total	42.618	81.54	37.598	111.80	20.010	64.63	30.834	213.96

TABLE II.—*Stand table for forest of northern Negros*—Continued.

Diameter of tree above buttresses in centimeters.	*Parashorea plicata* (bactican) and *Pentacme contorta* (white lauan).		Total dipterocarps.		All other species.[a]		Grand total.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
15	1.61	0.06	24.35	1.02			24.35	1.02
25	2.82	0.71	29.02	7.25			29.02	7.25
35	1.39	0.83	16.00	9.53			16.00	9.53
40	0.99	1.26	9.15	12.06	2.92	3.75	12.07	15.81
45	0.64	1.04	8.39	14.72	2.40	3.85	10.79	18.57
50	0.46	0.92	6.70	14.75	1.30	2.62	8.00	17.37
55	0.42	1.06	5.43	15.05	0.64	1.62	6.07	16.67
60	0.27	0.86	5.31	18.06	0.36	1.15	5.67	19.21
65	0.35	1.32	5.19	21.41	0.31	1.90	5.50	23.31
70	0.33	1.52	3.95	19.57	0.16	0.71	4.11	20.28
75	0.24	1.24	3.67	21.42	0.14	0.76	3.81	22.18
80	0.18	1.16	3.38	23.44	0.16	1.04	3.54	24.48
85	0.14	1.08	3.13	25.10	0.091	0.68	3.221	25.78
90	0.13	1.09	2.25	20.68	0.054	0.46	2.304	21.14
95	0.13	1.25	1.80	18.66	0.037	0.36	1.837	19.02
100	0.22	2.41	1.98	22.56	0.018	0.19	1.998	22.75
105	0.20	2.49	2.52	33.66	0.018	0.21	2.538	33.87
110	0.071	0.98	1.751	26.26			1.751	26.26
115	0.091	1.34	1.348	21.61			1.348	21.61
120	0.054	0.99	1.578	29.25			1.578	29.25
125	0.037	0.68	1.041	21.17			1.041	21.17
130	0.071	1.42	0.988	21.80			0.988	21.80
135	0.054	1.18	0.853	20.79			0.853	20.79
140	0.018	0.41	0.868	23.23			0.868	23.23
145			0.413	8.87			0.413	8.87
150			0.418	10.70	0.018	0.48	0.436	11.18
155			0.130	4.30			0.130	4.30
160	0.018	0.57	0.294	9.72			0.294	9.72
165								
170			0.092	3.16			0.092	3.16
Total	10.934	27.87	141.994	499.80	8.626	19.78	150.620	519.58

[a] Data for miscellaneous trees less than 40 centimeters in diameter are not available.

the main overmature stand is entirely removed in accordance with a management plan based on a diameter limit, we have left not a healthy, young, fast-growing stand, but a scattered stand of weak, slender poles, incapable of producing seed and often incapable of recovering from the suppression under which they have developed.

The undergrowth is much less dense than is usually the case in Philippine forests, due to the well-developed and extremely dense canopy and to the fact that this forest occurs on level or gently rolling land. Various kinds of erect palms occur scattered in all parts of the forest, as do rattans and other vines.

However, only in places where light has been admitted to the forest floor, due to a clearing or to a fallen tree, do rattans and other vines form the dense tangles so common in the poorly developed forests. The rattans and woody vines occur in sufficient quantity everywhere to give character to the forest, but the massive tree trunks are for the most part free from clinging vegetation and one's attention is attracted to them directly rather than to the minor constituents of the forest (Plate VI, fig. 1).

The heavy shade likewise prevents a dense herbaceous growth in the ground cover, which is scanty. The commonest plants in the ground cover are seedlings of the main tree species which thickly carpet the floor in many parts of the forest. It is a striking and very significant fact that tree seedlings below 7 centimeters in diameter are the most numerous of all the plants in the forest. The extraordinary abundance of these seedlings is shown in Table III.

The data shown in Table III bring out two important facts; namely, that small seedlings are present in large numbers, but due to the lack of light rarely develop into larger trees, and that small-sized poles are numerically the next most important tree class. It is to be noted, however, that these small poles which make up the bulk of the lower story are largely of species other than dipterocarps. From the above one might naturally conclude that if the main stand were removed without seriously injuring the stand of seedlings and small poles on the ground a thrifty rapid-growing young forest would be the result. Such would be the result with any forest in the temperate zone similarly constituted in regard to size classes, but unfortunately this is not the case in the Philippines. As will be shown later, it is, in the first place, entirely impossible to remove the main stand without practically destroying the understory. Secondly, the removal of the main stand carries with it the removal of almost the entire canopy, which results in the immediate death of almost all seedlings and of a large portion of the small poles.

Summing up, we see that we have in this class of forest a very overmature stand, almost exactly balanced between growth and decay, with the canopy and bulk of the stand concentrated in the largest size classes. The heavy shade cast by the main stand has prevented the development of an evenly graded understory which could be counted on to reproduce the forest and fill up the blanks made by the removal of the mature and overmature classes. The problem presented is that of removing within the

TABLE III.—*Reproduction surveys in virgin forests of Negros.*

Species.	Seedlings (up to 7 cms. in diameter).	Saplings (7 to 10 cms. in diameter).	Poles (10 to 30 cms. in diameter).	Standards (30 to 60 cms. in diameter).	Trees (above 60 cms. in diameter).
PLOT 1, 25 BY 100 METERS.					
Shorea negrosensis (red lauan)	569		5	2	6
Shorea eximia (almon)	193		5	4	
Diospyros sp. (ata-ata)	147	2	5	1	
Shorea polysperma (tanguile)	80				
Dipterocarpus grandiflorus (apitong)	56	13	34	10	1
All others	301	19	38	1	
Total	1,346	34	87	18	7
PLOT 2, 50 BY 100 METERS.					
Shorea negrosensis (red lauan)	1,270		13	10	11
Shorea eximia (almon)	982	2	14	10	4
Diospyros sp. (ata-ata)	178	3	18		
Shorea polysperma (tanguile)	300	2	3	5	2
Dipterocarpus grandiflorus (apitong)	205	3	18	11	
All others	466	36	62	2	
Total	3,401	46	128	38	17
PLOT 3, 25 BY 100 METERS.					
Shorea negrosensis (red lauan)	579	2	4	3	6
Shorea eximia (almon)	288		6	1	
Diospyros sp. (ata-ata)	98	4	11	1	
Shorea polysperma (tanguile)	73		2	2	
Dipterocarpus grandiflorus (apitong)	33	4	18	15	2
All others	288	22	41		
Total	1,359	32	82	22	8
PLOT 4, 50 BY 100 METERS.					
Shorea negrosensis (red lauan)	1,046		8	2	2
Shorea eximia (almon)	398	1	2	1	1
Diospyros sp. (ata-ata)	220	3	23		
Shorea polysperma (tanguile)	154		4	1	
Dipterocarpus grandiflorus (apitong)	110	6	56	21	3
All others	634	39	50	1	
Total	2,562	49	143	26	6

shortest possible rotation a large amount of accumulated wood capital which is not producing and which is, nevertheless, so integral a part of the forest that its removal endangers the very existence of the forest.

THE FOREST OF BATAAN

The southern part of Bataan Province, lying across the bay from Manila in latitude 14° 30′ north, is a mountainous region

with a central volcanic cone rising to an elevation of about 1,400 meters. This region differs from northern Negros in that it lacks the broad coastal plain, the ridges sloping directly to the sea. The ridges are narrow and steep, and the interior is badly broken up into knifelike ridges, running up to elevations of over 1,000 meters and separated by deep narrow valleys with steep rocky sides. The climate at elevations below 500 meters has a rather pronounced dry season lasting from December to the beginning of May. At higher elevations this is less noticeable. Whitford [17] gives the rainfall for this part of the province as follows:

TABLE IV.—*Rainfall, in millimeters, at Lamao, Bataan, and at Manila for parts of the year 1904–5.*

Month.	Lamao.	Manila.
December	trace	20.2
January	--------	0.0
February	0.0	2.8
March	0.8	1.1
April	127.0	[a]178.8
May	38.1	24.0
June	497.2	346.2
July	1,071.8	594.4
August	270.5	212.8
September	425.4	239.6

[a] The excessive rainfall for April is the highest ever recorded. It is mainly the amount which fell during the typhoon which visited the Islands on the 30th of that month.

The soil is a stiff loamy clay of volcanic origin, similar to that of northern Negros with the exception that it is probably less heavily charged with humus. Owing to the occurrence of a pronounced dry season, the surface layers of the soil are frequently much dryer than in northern Negros.

The forest under consideration lies on the eastern slope of Mount Mariveles to the west of Limay and Lamao barrios of the town of Orion, and extends from within a kilometer or so from the coast to an elevation of about 900 meters up the slopes of the mountain. The forest is distinctly dipterocarp in type at all elevations up to 800 meters, where it grades into a forest of miscellaneous smaller species, to which Whitford [18] has given the name *Eugenia-Vaccinium* formation, but at no elevation is there so large a proportion of dipterocarps as in the northern Negros forest.

The systematic composition of this forest has been thoroughly described by Whitford.[19] We need, therefore, do no more than

[17] *This Journal* (1906), 1, 379. [18] Ibid., 652. [19] Ibid., 384–431, 637–679.

point out such characteristics as are of interest from the standpoint of management. Due probably to the pronounced dry season and rough topography, the forests of Bataan are more complex in composition than are the forests of northern Negros. This is evident in the smaller size of the dipterocarps and in the larger number of smaller-sized trees of other families which enter the dominant story. The forest at various elevations is dominated by different dipterocarps, although these various species are represented at all elevations by scattered individuals. Below 250 meters the forest is dominated chiefly by *Anisoptera thurifera* (palosapis), from 250 meters to 450 meters by *Dipterocarpus grandiflorus* (apitong) and *Shorea polysperma* (tanguile), while above this *Shorea polysperma* is the commonest dipterocarp in the forest. There are several other dipterocarps scattered throughout the forest at all elevations, but in no place do these dominate the forest. The most prominent of these are *Pentacme contorta* (white lauan), *Dipterocarpus vernicifluus* (panao), *Hopea acuminata* (dalindingan), and *Shorea guiso* (guijo). At elevations of 450 meters and over, *Pentacme contorta* occurs sometimes in sufficient numbers to give character to the forest, but at the same time *Shorea polysperma* is present in larger numbers and is really the dominating species. Guijo, dalindingan, and panao do not occur in sufficient numbers to lend a distinctive character to the forest, and such other dipterocarps as have been reported from the area occur so rarely that they do not in any way affect the management of the area.

The lower part of the forest, which lies below 250 meters and in which *Anisoptera thurifera* is the predominant dipterocarp, is more complex and less distinctively dipterocarp in character than the forest of the next higher elevation. Thus, at low elevations where the forest has been continuously logged for many years the stand of timber is found to be an open irregular one in which dipterocarps are predominant as to size but not as to numbers. Due to the opening up of the area large numbers of fast-growing species, such as *Parkia timoriana* (cupang), *Zizyphus zonulatus* (balacat), *Albizzia procera* (acleng-parang), and *Lagerstroemia speciosa* (banaba), have entered or become more prominent, and over large areas an erect bamboo, *Schizostachyum mucronatum* (boho), occurs in such profusion as to give the forest anything but a dipterocarp character.

However, as we proceed up the lower mountain slope we enter a region which has been more difficult of exploitation for loggers who depend upon the most primitive forms of transportation, and we find the great body of the forest between elevations of

250 and 800 meters a decided dipterocarp type with patches where dipterocarps, especially *Shorea polysperma* (tanguile) and *Dipterocarpus grandiflorus* (apitong), occur in almost pure stands. However, the average stand covering fairly large areas does not show the predominance of dipterocarps common on areas of equal extent in Negros. Table V, computed from valuation measurements taken on 18.12 hectares, in one solid block, at elevations varying from 400 to 500 meters on the slopes of Mount Mariveles, Bataan, shows the volume and species composition of a typical stand (Plate VI, fig. 2).

Table V shows that in the Bataan forest the great bulk of the timber is between 50 centimeters and 100 centimeters in diameter, indicating that the trees do not attain the large diameters in this forest which are so commonly encountered in the forest of Negros. The fact that the forest of Bataan does not produce a uniform stand of exceptionally large-sized, overmature trees and that the main canopy is not so exclusively dipterocarp are the two main points of difference between this forest and that of Negros. The reason is, of course, that the site as a whole is not as favorable for the growth and development of dipterocarps as is the low, rolling, well-watered and well-drained plain of northern Negros. This less desirable site has resulted in giving an opportunity for other species, which are not the equal of the dipterocarps on the best sites, to develop, come to maturity, and reproduce themselves. The rough topography has resulted in a very uneven development of the stand in different situations, there being some exceptional patches which compare favorably with the average for northern Negros

TABLE V.—*Stand in 1 hectare based upon 18.12 hectares computed from valuation surveys in Bataan forest, showing number and volume of trees.*

[Volumes are given in cubic meters.]

Species.	Diameter class in centimeters.					
	30.		40.		50.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Dipterocarpus grandiflorus (apitong)	1.76	1.05	1.87	2.44	1.60	3.44
Dipterocarpus verniciflwus (panao)	3.75	2.25	2.53	3.22	1.93	4.15
Anisoptera thurifera (palosapis)	1.32	0.86	1.59	1.19	1.04	1.35
Shorea polysperma (tanguile)	2.42	1.65	2.15	2.68	1.71	3.45
Hopea acuminata (dalindingan)	0.98	0.16	0.55	0.60	0.38	0.78
Pentacme contorta (white lauan)	1.76	1.32	1.65	2.22	1.43	3.20
Shorea guiso (guijo)	1.32	0.87	0.77	0.99	0.38	0.78
All other species	13.96	6.16	8.88	8.91	5.40	10.44
Total	27.27	14.32	19.99	22.25	13.87	27.59
Total dipterocarps	13.31	8.16	11.11	13.34	8.47	17.15

TABLE V.—*Stand in 1 hectare based upon 18.12 hectares computed from valuation surveys in Bataan forest, showing number and volume of trees*—Continued.

Species.	Diameter class in centimeters.					
	60.		70.		80.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Dipterocarpus grandiflorus (apitong)	1.26	3.80	0.27	1.33	0.11	0.86
Dipterocarpus vernicifluus (panao)	1.15	4.12	0.38	2.29		
Anisoptera thurifera (palosapis)	0.60	1.33	0.41	1.58	0.11	0.54
Shorea polysperma (tanguile)	1.21	3.81	0.55	2.57	0.66	4.24
Hopea acuminata (dalindingan)	0.05	0.17	0.05	0.26	0.05	0.38
Pentacme contorta (white lauan)	0.88	2.99	0.22	1.07	0.11	0.74
Shorea guiso (guijo)	0.44	1.39	0.22	1.01		
All other species	2.75	8.77	0.71	3.46	0.33	2.12
Total	8.34	26.38	2.81	13.57	1.37	8.88
Total dipterocarps	5.59	17.61	2.10	10.11	1.04	6.76

Species.	Diameter class in centimeters.					
	90.		100.		110.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Dipterocarpus grandiflorus (apitong)	0.05	0.55	0.38	4.84		
Dipterocarpus vernicifluus (panao)	0.11	1.12	0.16	2.07		
Anisoptera thurifera (palosapis)	0.16	1.20	0.16	1.55	0.05	0.64
Shorea polysperma (tanguile)	0.27	2.29	0.60	6.66	0.27	3.80
Hopea acuminata (dalindingan)						
Pentacme contorta (white lauan)						
Shorea guiso (guijo)						
All other species	0.33	3.64	0.11	1.21		
Total	0.92	8.80	1.41	16.33	0.32	4.44
Total dipterocarps	0.59	5.16	1.30	15.12	0.32	4.44

Species.	Diameter class in centimeters.			
	120.		Total.	
	Trees.	Volume.	Trees.	Volume.
Dipterocarpus grandiflorus (apitong)			7.30	18.31
Dipterocarpus vernicifluus (panao)	0.05	0.88	10.06	20.10
Anisoptera thurifera (palosapis)			5.44	10.24
Shorea polysperma (tanguile)	0.22	3.70	10.06	34.85
Hopea acuminata (dalindingan)			2.06	2.35
Pentacme contorta (white lauan)			6.05	11.54
Shorea guiso (guijo)			3.13	5.04
All other species			32.47	44.71
Total	0.27	4.58	76.57	147.14
Total dipterocarps	0.27	4.58	44.10	102.43

and other patches in which the total volume is small. The average volume over large areas is, therefore, much less than in northern Negros.

The poorer development of the main story, resulting in the entrance of a large number of species other than dipterocarps, has produced well-developed second and third stories. For the same reason the undergrowth is denser, except on the ridges, than in forests where the main story is more prominent. This undergrowth is composed largely of tree seedlings, as is shown by Table VI.

TABLE VI.—*Reproduction plot, 5 by 50 meters, in forest of Bataan.*

Species.	Seedlings under 2 meters.	Diameter class in centimeters.							
		1.	2.	3.	4.	5.	6.	7.	8.
Shorea polysperma (tanguile)	5								
Dipterocarpus vernicifluus (panao)	3								
Dipterocarpus grandiflorus (apitong)	6	1							
Hopea acuminata (dalindingan)	12	1	1		1			1	
Pentacme contorta (white lauan)	219	1	1				1		
Shorea guiso (guijo)				1					
Anisoptera thurifera (palosapis)	2								
Eugenia sp. (macaasim)									
Calophyllum blancoi (palomaria)	140	2	1						
Miscellaneous trees	647	6	26	15	4	7	2	3	2
Miscellaneous brush	409								
Total	1,443	11	29	16	5	7	3	4	2
Total trees									
Total dipterocarps									

Species.	Diameter class in centimeters.							Total.
	9.	10.	20.	30.	40.	50.	Over 50.	
Shorea polysperma (tanguile)			1					6
Dipterocarpus vernicifluus (panao)								3
Dipterocarpus grandiflorus (apitong)								7
Hopea acuminata (dalindingan)				1			1	18
Pentacme contorta (white lauan)								222
Shorea guiso (guijo)								1
Anisoptera thurifera (palosapis)								2
Eugenia sp. (macaasim)		1					1	2
Calophyllum blancoi (palomaria)				1				144
Miscellaneous trees		9	2		2			725
Miscellaneous brush								409
Total		10	3	2	2		2	1,539
Total trees								1,130
Total dipterocarps								259

	Per cent.
Plants which are trees	73.4
Plants which are dipterocarps	16.7
Trees which are dipterocarps	23.0

Owing to the complex character of the forest and the prominence of a large number of trees other than dipterocarps, there are many more seedlings of other species than of dipterocarps. Nevertheless, the number of dipterocarp seedlings is greatly in excess of that found in the better-developed dipterocarp forest of northern Negros. These seedlings become established during the rainy season when the moist soil furnishes an excellent seed bed, and owing to the greater amount of light they are able to maintain themselves better than in the denser forest of northern Negros. This better development of the understories and ground cover is accompanied by a better distribution of the age classes of the dominant species. The forest is, therefore, much less overmature than that of Negros. There are, however, certain patches in the forest where the situation is especially favorable for the development of dipterocarps and which show the same overmature even-aged development as is found throughout the whole of the northern Negros forest. Table VII illustrates this character.

Were it not for the extreme difficulty of logging this area, due to the roughness of the topography, the forest would present a much easier management problem than one on a well-watered plain. In general, the problem presented by this forest is that of removing a mature and overmature crop of dipterocarp timber within as short a period of time as possible and of obtaining reproduction with dipterocarps as the leading species under a shelter wood, which for the most part will be made up of species other than dipterocarps. The companies which are interested in logging this kind of forest desire to remove dipterocarp species almost exclusively. If they are compelled by rational forest management to leave any timber on the ground, they much prefer to leave species other than dipterocarps; and any system of management which takes this problem of utilization into account must look as much to dipterocarp seedlings and poles already on the ground for reproduction as to dipterocarp seeds that may be sown in the area from the overmature trees which it is possible to leave in the remaining stand.

THE FOREST OF NORTHERN LAGUNA

The northeastern portion of Laguna Province, Luzon, is a plateau which rises on the west with an abrupt escarpment, some 300 meters in height, from Laguna de Bay. From the edge of this escarpment the plateau continues to rise gently toward the east to the divide between the Pacific Ocean and Laguna de Bay, the highest points in the plateau being from 500 to 600

TABLE VII.—*Stand of timber on 1 hectare of virgin forest, Bataan Province, Luzon, showing volume in cubic centimeters of each species and of each diameter class.*

Species.	Diameter class in centimeters.						
	5 to 35.	40.	50.	60.	70.	80.	90.
Shorea polysperma (tanguile)	3.28	1.68	3.15	4.55	19.00	10.60	53.73
Dipterocarpus grandiflorus (apitong)	7.23	8.83	10.62	33.09	23.47	22.99	55.01
Dipterocarpus vernicifluus (panao)	0.16						
Hopea acuminata (dalindingan)	2.65	0.84		5.86	3.73		
Shorea guiso (guijo)	2.30	1.54	1.74				
Pentacme contorta (white lauan)	1.12		1.74		3.10	7.03	
Anisoptera thurifera (palosapis)	0.29						
Eugenia sp. (macaasim)	2.65	1.13					
Callophyllum blancoi (palomaria)	2.25	2.81					
Strombosia philippinensis (tamayuan)	0.93	0.84					
Miscellaneous species	24.07	12.50	7.57	12.78	8.06	10.34	
Total	46.93	30.17	24.82	56.28	57.36	50.96	108.74

Species.	100.	110.	120.	130.	140.	Total.
Shorea polysperma (tanguile)			38.86			134.85
Dipterocarpus grandiflorus (apitong)	24.90	15.75	38.86			240.75
Dipterocarpus vernicifluus (panao)						0.16
Hopea acuminata (dalindingan)						13.08
Shorea guiso (guijo)						5.58
Pentacme contorta (white lauan)			19.43			32.42
Anisoptera thurifera (palosapis)	10.94				27.90	39.13
Eugenia sp. (macaasim)						3.78
Callophyllum blancoi (palomaria)						5.06
Strombosia philippinensis (tamayuan)						1.77
Miscellaneous species						75.32
Total	35.84	15.75	97.15		27.90	551.90

	Cubic meters.
Trees less than 50 centimeters in diameter	80.409
Dipterocarps less than 50 centimeters in diameter	32.283
Trees more than 50 centimeters in diameter	471.49
Dipterocarps more than 50 centimeters in diameter	433.69

meters in elevation. Directly to the east of Laguna de Bay there is very little difference of elevation over large areas. Farther to the north, the country rises to the foothills of the main cordillera of Luzon, becoming very rough and broken, while to the south the region rises gently to meet the lower slopes of Mount Banahao. The main drainage throughout the central and southern portion of the region is the Pagsanjan River, which empties into Laguna de Bay below Pagsanjan. Throughout this plateau all the smaller streams are very irregular in their courses, and lie in narrow valleys from 20 to 30 meters below the general level

of the plateau. The soil, which is a deep, stiff, red clay, is rather poorly drained. The forest lies some 6 or 8 kilometers to the east of Laguna de Bay, and extends to the Pacific. The area between the edge of the forest and the lake has been cleared to permit cultivation.

The climate throughout the area is very distinctly that of the nonseasonal belt. The season of heaviest rain is from June to December, but the northeast monsoon rising from the Pacific over the rather abrupt elevation of the Pacific slope deposits considerable rain throughout the balance of the year. During the months from December to June the rainfall is heaviest on the eastern side of the forest near the Pacific, becoming gradually less toward the western edge of the forest. A rather heavy bank of clouds lies over the forest at almost all periods of the year, and is very evident on the horizon as the forest is approached over the cleared portion of the elevated plateau between the forest and the lake on the west.

The forest is very distinctly dipterocarp in character throughout the whole region. Due to the fact that changes in elevation in the area are not appreciable, the composition of the forest remains very similar throughout all parts of it. The dominant story is composed almost entirely of dipterocarps, the two most prominent being *Shorea teysmanniana* (tiaong) and *Shorea squamata* (mayapis). Associated with these in the dominant

TABLE VIII.—*Stand table for 1 hectare (average of 6 hectares), northern Laguna forest, showing number and volume of each species.*

[Volumes are given in cubic meters.]

Species.	Diameter class in centimeters.							
	30.		35.		40.		50.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Shorea squamata (mayapis)	5.32	2.56	1.21	1.23	12.83	13.00	8.66	17.75
Shorea teysmanniana (tiaong lauan)	3.16	1.55	1.15	0.83	7.32	8.00	5.99	12.28
Shorea polysperma (tanguile)	0.82	0.41	1.82	1.35	1.14	2.67	2.65	6.36
Dipterocarpus sp. (apitong)	1.49	0.72			1.98	1.62	0.65	2.06
Pentacme contorta (white lauan)	0.66	0.32			1.82	1.44		
Dipterocarpus sp. (panao)	0.66	0.32			0.33	0.36	0.16	0.34
Hopea pierrei (dalindingan isak)	3.16	1.55	2.99	2.03	1.15	5.63	2.49	5.10
Total dipterocarps	15.27	7.43	7.17	5.44	26.57	32.72	20.60	43.89
Total, all other species	7.82	3.44	4.32	2.64	13.15	13.16	3.16	6.10
Grand total	23.09	10.87	11.49	8.08	39.72	45.88	23.76	49.99

TABLE VIII.—*Stand table for 1 hectare (average of 6 hectares), northern Laguna forest, showing number and volume of each species*— Contd.

Species.	Diameter class in centimeters.							
	60.		70.		80.		90.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Shorea squamata (mayapis)	3.16	10.70	0.65	4.09	0.48	3.94		
Shorea teysmanniana (tiaong lauan)	2.98	9.88	0.71	6.22	0.70	7.56	0.16	1.55
Shorea polysperma (tanguile)	0.82	2.75	1.15	5.85	0.81	5.64	0.16	3.11
Dipterocarpus sp. (apitong)			0.33	1.75				
Pentacme contorta (white lauan)	0.33	1.13			0.16	1.66		
Dipterocarpus sp. (panao)			0.16	0.87				
Hopea pierrei (dalindingan isak)								
Total dipterocarps	7.29	24.46	3.00	18.78	2.15	18.80	0.32	4.66
Total, all other species	1.49	4.73	0.66	3.54				
Grand total	8.78	29.19	3.66	22.32	2.15	18.80	0.32	4.66

Species.	Diameter class in centimeters.			
	100.		Total.	
	Trees.	Volume.	Trees.	Volume.
Shorea squamata (mayapis)			32.31	53.27
Shorea teysmanniana (tiaong lauan)	0.16	2.01	22.33	49.88
Shorea polysperma (tanguile)	0.99	12.09	10.36	40.23
Dipterocarpus sp. (apitong)			4.45	6.15
Pentacme contorta (white lauan)			2.97	4.55
Dipterocarpus sp. (panao)			1.31	1.89
Hopea pierrei (dalindingan isak)			9.79	14.31
Total dipterocarps	1.15	14.10	83.52	170.28
Total, all other species			30.60	33.61
Grand total	1.15	14.10	114.12	203.89

story are *Shorea polysperma* (tanguile), species of *Dipterocarpus* (apitong and panao), and a number of other dipterocarps. *Hopea pierrei* (dalingdingan-isak) is the principal second-story tree, and occurs in large numbers everywhere, except near the edge of the forest where it has been largely removed by logging.

The above species occur in mixture with *Machilus philippinensis* (baticulin), *Palaquium* spp. (nato), *Vitex* sp. (sasalit), *Astronia* spp. (dungao), *Mastixia philippinensis* (tapulao), *Dillenia* sp. (malacatmon), and others, but the percentage of dipterocarps both as to number of trees and total volume is almost as great as in the forest of Negros, although the total volume of the forest is much less. The data in Table VIII, com-

puted from valuation surveys on 6 hectares at different points in the area, are fairly typical of the stand in this forest.

A review of Table VIII shows that this forest differs from those previously discussed in that, although it is dipterocarp in composition, it is a forest of smaller-sized trees and is very distinctly not overmature. Due to the elevation at which the forest occurs and to the presence of rather heavy clouds over the area at almost all seasons, the site as a whole is less desirable than that of Negros for the development of a large forest, and the result has been that although dipterocarps have claimed the area almost to the exclusion of other dominant species they have not been able to dominate it sufficiently to produce an even-aged forest of but a few species. Each species in the area is represented more by trees of the smaller diameter classes than by large overmature specimens.

The main canopy is even more irregular and open than that of the better parts of the forest of Bataan, and this has resulted in a very well-developed lower story and a dense undergrowth (Plate VIII, fig. 1). The undergrowth is made up almost entirely of tree seedlings, to a very large extent of those of dipterocarps. The excessively moist soil and high relative humidity furnish the dipterocarps excellent conditions for germination, and over large areas dipterocarp seedlings, particularly those of *Hopea pierrei*, a meter or less in height, form dense thickets.

As is true in all forests, certain patches may be found throughout the area where the situation is more favorable to the development of the predominant group, the dipterocarps, and in these patches the forest approaches the overmature character of the other forests discussed, but in no place does this become sufficiently pronounced to necessitate serious consideration in the management of the area. The data in Table IX, from a patch of forest of 44,100 square meters, illustrate the best development attained by the forest of this region.

Certain portions of this forest lying within easy logging distance of large wood-using communities have been continuously logged over for many years in a desultory manner with a diameter-limit regulation of 40 centimeters. Practically the only effect of this operation on the forest has been to reduce the percentage of large specimens of the more desirable species, such as dalindingan isak, macaasim, tanguile, and baticulin—the dipterocarp character of the forest being little changed. This is, of course, largely due to the fact that the logging itself has been very selective in character and has not sought dipterocarps as the main product. However, the satisfactory distri-

TABLE IX.—*Stand table for 1 hectare. Northern Laguna forest, Laguna Province, Luzon.*

[Based on surveys of 44,100 square meters. Volumes are given in cubic meters.]

Species.	Diameter class in centimeters.								
	45.	55.	65.	75.	85.	95.	105.	125.	Total.
Pentacme contorta, *Shorea teysmanniana*, *Shorea squamata* (lauans)	41.50	45.35	50.15	28.10	9.08	2.42	9.19	452	190.31
Dipterocarpus sp. (apitong)	8.89	8.53	5.88	1.44	3.41				28.15
Hopea pierrei (dalindingan isak)	11.41	8.28	3.63	1.37					24.69
Miscellaneous	14.45	10.71	8.08						33.24
Total	76.25	72.87	67.74	30.91	12.49	2.42	9.19	4.52	276.39

bution of trees of different diameters is a factor in the result, and from a management standpoint this forest approaches as nearly the ideal, in regard to composition and the distribution of volume throughout the different size classes, as could be expected of any natural forest in the Philippines. The even distribution of all species throughout a large range of diameters makes the forest thoroughly suited to the selection system of management, which is preëminently the system most suited to forests in which the species are tolerant in youth and later develop into large distinctly intolerant trees. The forest is one of the few in the Islands which could be satisfactorily managed with a diameter limit as the sole managerial regulation, and the problem presented is merely that of the removal of mature trees, which, with careful logging, can be accomplished without endangering the existence or the reproductive power of the forest.

THE DIPTEROCARP FOREST OF MOUNT MAQUILING

Mount Maquiling is an isolated volcanic cone situated on Luzon midway between the eastern and western coasts, about 64 kilometers southeast of Manila in latitude 14° 10′ north and longitude 122° east of Greenwich. The climate of the region is distinctly monsoon in character, but the dry season, although pronounced on the eastern side, is very much less severe than on the western side. On the dry western side the forest to a large extent has been replaced by grass areas. The soil of the eastern side is a heavy reddish brown clay of volcanic origin heavily charged with humus. The forest under discussion is located on the eastern and southeastern slopes, extending from the cleared land at the base of the mountain, at elevations of

from 50 to 100 meters to elevations of 600 meters, where the dipterocarp forest gives way to mountain-top forms. The topography of this section of the mountain may be described as a series of radiating, broad, well-drained ridges separated by narrow valleys.

The forest is located in the center of a well-populated district, and has been subjected to a process of selective logging for many years. The trees most valuable for commercial purposes have been almost entirely removed from the forest at all elevations below 400 meters. The dipterocarps which originally made up a large portion of the forest cover were probably *Parashorea plicata* (bagtican-lauan), *Shorea guiso* (guijo), *Pentacme contorta* (white lauan), and *Hopea acuminata* (dalindingan or mangachapuy). Representatives of these species in the seedling and sapling classes are to be found well distributed over the mountain and in the case of guijo and white lauan in sufficient numbers to indicate that there was a considerable stand of these two species on the lower slopes not over seventy-five years ago. Guijo and white lauan are in great demand throughout the surrounding communities for the construction of bancas, and dalindingan, being a close relative of yacal, is everywhere in demand for house construction. Bagtican-lauan, not being especially desirable for either of the above uses, has suffered less than any of the other dipterocarps, and remains as one of the main species in both the main and the understory of the forest. This condition is not the result of a few years' active logging. The change has come about slowly, and a dipterocarp forest such as the situation indicates probably has not existed on the lower slopes of this mountain for as much as from one hundred fifty to two hundred years.

As is to be expected, the result of this selective logging has been to favor the species which would normally exist in the understory to such an extent that they occupy the dominant situation normally held by the dipterocarps. Species, which due to their persistence remain as inconspicuous elements in a normal undisturbed forest, without ever becoming entirely eliminated, have increased in numbers, and others, which under the shade of a heavy dipterocarp crown cover rarely reach noticeable size, have developed so as to become prominent components of the main stand. Thus, the present forest, although possibly not any more complex than originally with respect to the absolute number of species, is apparently of very mixed character because so many species have come into the main story.

The most accessible portions of the forest are those extending

from 1 to 2 kilometers from the edge and up to elevations of 200 meters. They have been so heavily logged that the main canopy has almost entirely disappeared and only remnants of the lower stories remain. The entrance of light to the forest floor in these places has permitted a tremendous development of climbing bamboo, rattans, and vines of various kinds (Plate VIII, fig. 2). The trees are mostly small, but are fairly numerous. The forest is, therefore, a low dense tangle. The drying out of the soil in such situations prevents the easy germination of high-forest species, and although logging has practically ceased, the jungle growth still maintains the upper hand and the change back to a forest of commercial species is being accomplished very slowly.

The forest lying next to this belt and up to 400 meters in elevation has been logged over more slowly, and although the best specimens of the dipterocarps, with the exception of bagtican-lauan, which here has probably always been the dominant species, have been almost entirely removed, the climatic condition of the forest has not been seriously changed and the smaller classes of the more valuable species are present in sufficient numbers to insure the reproduction of the original type of forest if placed under management (Plate I, fig. 1, and Plate IX, fig. 1).

Above 400 meters logging has not been carried on to any considerable extent and what is probably the original character of the forest remains unchanged. Scattered specimens of bagtican-lauan are to be found as high as 600 meters, but here species of *Quercus* and *Dillenia* are more prominent. At 800 meters these species occur less frequently, and the forest begins to change into the mossy type which extends from an elevation of approximately 1,000 meters to the summit of the mountain.

The following stand table (Table X), compiled from data gathered at an elevation of approximately 140 meters, shows clearly the character of the forest after selective logging has been completed. [See pages 444 and 445.]

Out of a total of 319 trees 15 centimeters and over in diameter on 1 hectare, only 4 dipterocarps are reported, 3 of these being of one species, *Parashorea plicata* (bagtican-lauan). The volume is extremely low (122.83 cubic meters), and as may be judged from the fact that over 50 per cent of the volume lies in the diameter classes below 40 centimeters, the main canopy has almost entirely disappeared. Furthermore, the extremely mixed character of the stand is well illustrated by the fact that 61 per cent of the stand by volume is distributed throughout 27 listed species, while the remaining 39 per cent is distributed among

TABLE X.—*Stand on 1 hectare of over-cut forest on Mount Maquiling, Laguna, Luzon, showing number of trees and volume in cubic meters of each species.*

Species.	Diameter class in centimeters.									
	15.		25.		35.		45.		55.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Pahudia rhomboidea (tindalo)			1	0.25			1	1.42		
Lagerstroemia speciosa (banaba)	1									
Shorea guiso (guijo)	1									
Tarrietia sylvatica (dungon)							1	1.42		
Sideroxylon sp. (white nato)										
Sandoricum koetjape (santol)							2	2.84		
Dillenia philippinensis (catmon)					1	0.69				
Koordersiodendron pinnatum (amuguis)			2	0.50						
Parkia timoriana (cupang)			2	0.50	1	0.69				
Polyscias nodosa (malapapaya)			1	0.25						
Alstonia macrophylla (batino)					1	0.69			1	2.49
Strombosia philippinensis (tamayauan)	2									
Mallotus philippensis (banato)	1									
Canarium sp. (pili)			1	0.25	1	0.69				
Anonaceae (lanutan)	1		1	0.25						
Alangium meyeri (putian)			1	0.25			1	1.42		
Myristica philippensis (duguan)	1									
Streblus asper (kalios)			1	0.25						
Planchonia spectabilis (lamog)			3	0.75					1	2.49
Canangium odoratum (ylang-ylang)					1	0.69			1	2.49
Diplodiscus paniculatus (balobo)	30		35	8.75	9	6.21	6	8.52		
Parashorea plicata (bagtican)			1	0.25			1	1.42	1	2.49
Garcinia binucao (binucao)	2		4	1.00	1	0.69				
Celtis philippensis (malaicmo)			1	0.25	1	0.69				
Dracontomelum cumingianum (lamio)			1	0.25	3	7.07				
Bischofia javanica (tuai)										

TABLE X.—*Stand on 1 hectare of over-cut forest on Mount Maquiling, Laguna, Luzon, showing number of trees and volume in cubic meters of each species*—Continued.

Species.	Diameter class in centimeters.									
	15.		25.		35.		45.		55.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Trewia ambigua (batobato)	1	------	------	------	2	1.38	------	------	------	------
Miscellaneous	127	------	35	8.75	10	6.90	6	8.52	1	2.49
Total	167	------	90	22.50	31	21.39	18	25.56	5	12.45
Percentage of stand	52.5	------	28.3	18.05	9.8	17.15	5.3	20.45	1.6	11.55

Species.	Diameter class in centimeters.				Total trees.	Percentage of stand by number.	Total volume.	Percentage of stand by volume.
	65.		75.					
	Trees.	Volume.	Trees.	Volume.				
Pahudia rhomboidea (tindalo)	------	------	------	------	2	0.63	1.67	1.36
Lagerstroemia speciosa (banaba)	------	------	------	------	1	0.31	------	------
Shorea guiso (guijo)	------	------	------	------	1	0.31	------	------
Tarrietia sylvatica (dungon)	------	------	1	5.81	2	0.63	7.23	5.89
Sideroxylon sp. (white nato)	1	3.96	------	------	1	0.31	3.96	3.22
Sandoricum koetjape (santol)	------	------	------	------	2	0.63	2.84	2.31
Dillenia philippinensis (catmon)	------	------	------	------	1	0.31	0.69	0.56
Koordersiodendron pinnatum (amuguis	------	------	------	------	2	0.63	0.50	0.41
Parkia timoriana (cupang)	------	------	------	------	3	0.94	1.19	0.97
Polyscias nodosa (malapapaya)	------	------	------	------	1	0.31	0.25	0.20
Alstonia macrophylla (batino)	------	------	------	------	2	0.63	3.18	2.59
Strombosia philippinensis (tamayauan)	------	------	------	------	2	0.63	------	------
Mallotus philippensis (banato)	------	------	------	------	1	0.31	------	------
Canarium sp. (pili)	------	------	1	5.81	3	0.94	6.75	5.49
Anonaceae (lanutan)	------	------	------	------	2	0.63	0.25	0.20
Alangium meyeri (putian)	------	------	------	------	2	0.63	1.67	1.36
Myristica philippensis (duguan)	------	------	------	------	1	0.31	------	------
Streblus asper (kalios)	------	------	------	------	1	0.31	0.25	0.20
Planchonia spectabilis (lamog)	------	------	------	------	4	1.26	3.24	2.64
Canangium odoratum (ylang-ylang)	------	------	------	------	2	0.63	3.18	2.59
Diplodiscus paniculatus (balobo)	------	------	------	------	80	25.07	23.48	19.11
Parashorea plicata (bagtican)	------	------	------	------	3	0.94	4.16	3.39
Garcinia binucao (binucao)	------	------	------	------	7	2.19	1.69	1.38
Celtis philippensis (malaicmo)	------	------	------	------	2	0.63	0.94	0.77
Dracontomelum cumingianum (lamio)	------	------	------	------	4	1.26	2.32	1.89
Bischofia javanica (tuai)	1	3.96	------	------	1	0.31	3.96	3.22
Trewia ambigua (batobato)	------	------	------	------	3	0.94	1.38	1.12
Miscellaneous	1	3.96	3	17.43	183	57.37	48.05	39.13
Total	3	11.88	5	29.05	319	100.00	122.83	100.00
Percentage of stand	0.9	9.55	1.6	23.25	100	------	------	------

miscellaneous species so varied in character as to be impracticable of identification by casual inspection.

Table XI, compiled from data gathered at an elevation of 250 meters and over a kliometer from the edge of the forest, is a typical illustration of the better parts of the forest below 300 meters in elevation.

TABLE XI.—*Stand on 1 hectare, altitude 250 meters, on Mount Maquiling, Laguna, Luzon, showing number of trees and volume in cubic meters of each species.*

Species.	Diameter class in centimeters.							
	15.		25.		35.		45.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Diospyros sp	18	1.26	4	1.04	2	1.38		
Shorea guiso (guijo)			2	0.52	1	0.69		
Dillenia philippinensis (catmon)	2	0.14	6	1.56	1	0.69	3	4.26
Strombosia philippinensis (tamayuan)	1	0.07						
Diplodiscus paniculatus (balobo)	18	1.26	26	6.67	17	11.73	7	9.94
Parashorea plicata (bagtican)	5	0.35	13	3.38	4	2.76	4	5.68
Zizyphus zonulatus (balacat)			1	0.26				
Trewia ambigua (batobato)	1	0.07						
Canarium sp	2	0.14	1	0.26	2	1.38	1	1.42
Eugenia sp					1	0.69		
Ficus spp	2	0.14			1	0.69		
Polyalthia and other Anonaceae (lanutan)	4	0.28	1	0.26				
Pentacme contorta (white lauan)			1	0.26				
Planchonia spectabilis (lamog)			1	0.26				
Celtis spp. (malaikmo)			1	0.26	4	2.76	2	2.84
Macaranga spp	2	0.14	1	0.26	1	0.69		
Pterocymbium tinctorium (taluto)							1	1.42
Cyclostomon sp. (tinaan pantay)			1	0.26	4	2.76		
Miscellaneous	123	8.61	50	13	22	15.18	10	14.2
Total	178	12.46	109	28.25	60	41.40	28	39.76
Per cent of stand	44.14	4.4	27.4	10.1	14.58	14.9	6.95	14.2

Species.	Diameter class in centimeters.							
	55.		65.		75.		85.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Diospyros sp								
Shorea guiso (guijo)								
Dillenia philippinensis (catmon)	1	2.49						
Strombosia philippinensis (tamayuan)								
Diplodiscus paniculatus (balobo)	2	4.98						
Parashorea plicata (bagtican)	1	2.49	1	3.96	1	5.81	2	16.22
Zizyphus zonulatus (balacat)								
Trewia ambigua (batobato)								

TABLE XI.—*Stand on 1 hectare, altitude 250 meters, on Mount Maquiling, Laguna, Luzon, showing number of trees and volume in cubic meters of each species*—Continued.

Species.	Diameter class in centimeters.							
	55.		65.		75.		85.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
Canarium spp			1	3.96				
Eugenia spp								
Ficus spp								
Polyalthia and other Anonaceae (lanutan)								
Pentacme contorta (white lauan)							1	8.11
Planchonia spectabilis (lamog)								
Celtis spp. (malaikmo)	4	9.96	3	11.88			1	8.11
Macaranga spp								
Pterocymbium tinctorium (taluto)								
Cyclostomon sp. (tinaan pantay)								
Miscellaneous	2	4.98	1	3.96	2	11.62		
Total	10	24.90	6	23.76	3	17.43	4	32.44
Per cent of stand	2.48	8.9	1.49	8.5	0.74	6.2	0.99	11.7

Species.	Diameter class in centimeters.							
	95.		105.		Total trees.	Stand by number of trees.	Total volume.	Stand by volume.
	Trees.	Volume.	Trees.	Volume.				
						P. ct.	Cu. m.	P. ct.
Diospyros sp					24	5.95	3.68	1.32
Shorea guiso (guijo)					3	0.74	1.21	0.44
Dillenia philippinensis (catmon)					13	3.24	9.14	3.29
Strombosia philippinensis (tamayuan)					1	0.28	0.07	0.03
Diplodiscus paniculatus (balobo)					70	17.38	34.58	12.44
Parashorea plicata (bagtican)			2	24.18	33	8.18	64.83	23.31
Zizyphus zonulatus (balacat)					1	0.25	0.26	0.09
Trewia ambigua (batobato)					1	0.25	0.07	0.03
Canarium spp	1	10.71			8	1.99	17.87	6.44
Eugenia spp					1	0.25	0.69	0.25
Ficus spp					3	0.74	0.83	0.30
Polyalthia and other Anonaceae (lanutan)					5	1.24	0.54	0.19
Pentacme contorta (white lauan)			1	12.09	3	0.74	20.46	7.36
Planchonia spectabilis (lamog)					1	0.25	0.26	0.09
Celtis spp. (malaikmo)	1	10.71			16	3.97	46.52	16.73
Macaranga spp					4	0.99	1.09	0.39
Pterocymbium tinctorium (taluto)					1	0.24	1.42	0.52
Cyclostomon sp. (tinaan pantay)					5	1.25	3.02	1.08
Miscellaneous					210	52.10	71.55	25.70
Total	2	21.42	3	36.27	403		278.09	
Per cent of stand	0.49	7.7	74	13.4	100	100	100	100

The stand of timber shown here is much heavier and is distributed throughout a smaller number of species. In 403 trees on 1 hectare, the volume of 206 cubic meters, of a total of 278 cubic meters, is distributed among 18 listed species and but 26 per cent of the volume occurs in trees that were impracticable of identification by inspection. Furthermore, 3 species of dipterocarps were reported on 1 hectare—guijo, represented by 3 trees; bagtican-lauan, represented by 33 trees; and white lauan, represented by 3 trees.

At elevations of from 400 to 600 meters, and at some lower elevations in the more inaccessible parts of the forest, we find the original forest in an almost undisturbed condition. For the most part, however, this original forest is rather poor in quality, due to the fact that it occurs on the upper fringe of the dipterocarp belt and in part on steep slopes with shallow soils. The total area of this class of forest when compared with the area around the outside of the forest, which has been logged over, is relatively insignificant. However, it gives us some indication of what the forest was at lower elevations.

In Table XII, compiled from information gathered in a small area of virgin forest at an elevation of 450 meters, are given exact data as to the composition and volume of one-quarter of 1 hectare.

TABLE XII.—*Stand of trees over 2 meters in height on 0.25 hectare. Altitude 450 meters on Mount Maquiling, Laguna Province, Luzon.*

No.	Species.	Individuals.	Volume.[a]			Greatest height on plot.	Greatest diameter on plot.	Story to which tree belongs.
			Total.	Diameter classes 10–40 cm.	Diameter classes 40 cm. and over.			
	Dipterocarps:		*cu. m.*	*cu. m.*	*cu. m.*	*m.*	*cm.*	
1	*Parashorea plicata* (bagtican lauan)	29	18.47	2.65	15.82	35.95	96.0	1
2	*Shorea guiso* (guijo)	4	0.09	0.09		10.50	15.0	1
3	*Hopea acuminata* (dalindingan)	1				2.40	2.0	1
	Miscellaneous species:							
4	*Bischofia javanica* (tuai)	1	4.31		4.31	21.00	72.0	1
5	*Canarium luzonicum* (pili)	2	3.04		3.04	23.60	58.0	1
6	*Canarium villosum* (pagsahingin)	1				5.80	6.0	1
7	*Canarium* sp. (pagsahingin)	6	0.07	0.07		10.10	17.0	1
8	*Canarium* sp	1				4.90	5.0	1
9	*Celtis philippensis* (malaicmo)	11	0.14	0.14		18.35	15.0	1
10	*Eugenia similis* (malaruhat)	3	8.92		8.92	26.00	95.0	1
11	*Eugenia luzonensis* (malaruhat puti)	2	0.05	0.05		6.85	13.0	1
12	*Eugenia mananquil*	2				3.00	2.5	1?
13	*Eugenia* sp	1				2.30	2.5	1?
14	*Meliosma macrophylla*	4	0.46	0.46		21.25	25.0	1

TABLE XII.—*Stand of trees over 2 meters in height on 0.25 hectare. Altitude 450 meters on Mount Maquiling, Laguna Province, Luzon*—Contd.

No.	Species.	Individuals.	Volume.[a] Total.	Diameter classes 10-40 cm.	Diameter classes 40 cm. and over.	Greatest height on plot.	Greatest diameter on plot.	Story to which tree belongs.
	Miscellaneous species—Continued.		*cu. m.*	*cu. m.*	*cu. m.*	*m.*	*cm.*	
15	*Nauclea* sp	4	5.38	1.13	4.25	28.40	50.0	1
16	*Palaquium tenuipetiolatum* (palac-palac)	2	0.22	0.22		22.65	20.0	1
17	*Planchonia spectabilis* (lamog)	2	7.87		7.87	28.30	75.0	1
18	*Palaquium* sp	3				4.30	3.0	1
19	*Palaquium* sp	2				2.00	2.0	1
20	*Pterocymbium tinctorium* (taluto)	1				2.50	1.5	1
21	*Sterculia* sp. (lapnit)	1	6.35		6.35	32.10	83.0	1
22	*Turpinia pomifera* (malabago)	4	0.36	0.36		17.55	25.0	1
23	*Diplodiscus paniculatus* (balobo)	28	1.37	1.37		13.00	34.0	2
24	*Aglaia diffusa* (salaquin pula)	1				2.10	1.5	2
25	*Aglaia* sp. (malasaguing)	11	0.38	0.38		17.10	30.0	2
26	*Alangium meyeri* (putian)	5	0.03	0.03		13.55	14.0	2
27	*Amoora* sp	5				6.00	8.0	2
28	*Ardisia perrotettiana*	3				9.20	8.0	2
29	*Ardisia* sp	1				2.70	2.0	2
30	*Ardisia boissieri* (tagpo)	4	0.39	0.39		14.15	25.0	2
31	*Chisochiton philippinus* (salaquin pula)	1				2.00	2.0	2
32	*Chisochiton cummingianus* (salaquin puti)	8	0.05	0.05		11.65	15.0	2
33	Indt	1	0.21	0.21		17.40	25.0	2
34	*Cinnamomum mercadoi* (calingag)	3	0.51	0.51		20.00	30.0	2
35	*Cryptocarya lauriflora*	2				5.60	4.5	2
36	*Cyclostemon* sp	3				4.17	4.5	2
37	*Dillenia philippinensis* (catmon)	16	5.36	2.31	3.05	17.00	55.0	2
38	*Dillenia reifferscheidia* (catmon)	1	0.78		0.78	14.20	45.0	2
39	*Diospyros discolor* (camagon)	9	3.21	1.46	1.75	22.00	50.0	2
40	*Dysoxylon* sp	4				2.80	3.0	2
41	*Euphoria cinerea* (alupag)	1				2.10	2.0	2
42	*Euonymus javanica*	3				2.45	2.0	2
43	*Evodia* sp	1	0.33	0.33		16.55	25.0	2
44	*Ficus* sp	2	0.98	0.98		20.15	38.0	2
45	*Ficus barnesii*	1	0.05	0.05		13.14	20.0	2
46	*Ficus ribes* (aumit)	6	0.16	0.16		12.50	15.0	2
47	*Ficus variegata* (tangisang biawak)	6	1.60	1.60		20.35	35.0	2
48	*Garcinia venulosa* (gatasan)	2	0.07	0.07		9.80	16.0	2
49	*Garcinia binucao* (binucao)	1				2.95	2.5	2
50	*Gymnacranthera paniculata* (tambalao)	2				3.10	4.0	2
51	*Litsea garciae*	3	1.12	1.12		17.50	35.0	2
52	*Lophopetalum toxicum* (kalatumbago)	3	1.11	1.11		24.00	30.0	2
53	*Livistona* sp. (anahao)	13				18.00	21.0	2
54	*Maxtixia philippinensis* (tapulao)	3				3.07	8.0	2
55	*Memecylon paniculatum* (culis)	2				2.10	2.5	2
56	*Nauclea media*	1				5.35	8.0	2
57	*Nauclea calycina*	3	0.06	0.06		16.85	21.0	2

TABLE XII.—*Stand of trees over 2 meters in height on 0.25 hectare. Altitude 450 meters on Mount Maquiling, Laguna Province, Luzon*—Contd.

No.	Species.	Individuals.	Volume.[a] Total.	Diameter classes 10-40 cm.	Diameter classes 40 cm. and over.	Greatest height on plot.	Greatest diameter on plot.	Story to which tree belongs.
	Miscellaneous species—Continued.		*cu. m.*	*cu. m.*	*cu. m.*	*m.*	*cm.*	
58	*Nephelium mutabile* (bulala)	10	1.69	0.56	1.13	23.00	42.0	2
59	*Pisonia umbellulifera* (anuling)	1				7.20	8.0	2
60	*Polyalthia lanceolata* (lanutan)	3				9.20	11.0	2
61	*Symplocos* sp	1				3.20	3.5	2
62	*Sarcocephalus junghuhnii* (mambog)	4	0.38	0.38		13.00	25.0	2
63	*Semecarpus gigantifolius* (ligas)	1	0.43	0.43		19.00	30.0	2
64	*Strombosia philippinensis* (tamayuan)	1				3.90	3.0	2
65	*Terminalia pellucida* (calumpit)	1				8.15	8.0	2
66	*Ficus minahassae* (hagimit)	1				10.05	3.0	3
67	*Flacourtia* sp	2				2.40	2.0	3
68	*Garcinia rubra*	1				7.00	7.0	3
69	*Glochidion* sp	2				4.06	6.0	3
70	*Glochidion lancifolum*	1				3.07	3.0	3
71	*Goniothalamus elmeri*	3				4.40	5.0	3
72	*Grewia stylocarpa* (susumbik)	9	0.01	0.01		10.72	17.0	3
73	*Ixora longistipula*	1				2.20	2.0	3
74	*Ixora macrophylla*	2				6.15	6.0	3
75	*Laportea subclausa* (lipa)	12	0.02	0.02		10.20	10.0	3
76	*Leea philippinensis*	2	0.02	0.02		10.90	10.0	3
77	*Leea manillensis*	15				11.20	8.0	3
78	*Leea aculeata*	3				2.90	3.0	3
79	*Leucosyke capitellata* (lagasi)	1				3.30	3.0	3
80	*Macaranga grandifolia* (taquip asin)	3	0.03	0.03		12.40	15.0	3
81	*Macaranga bicolor* (hamindang)	1	0.06	0.06		11.60	12.0	3
82	*Mallotus ricinoides* (hinlaumo)	1				2.50	2.0	3
83	*Neolitsea villosa*	2	0.03	0.03		8.95	10.0	3
84	*Oreocnide trinervis*	9	0.01	0.01		8.25	12.0	3
85	*Saurauia latibracteata*	2	0.17	0.17		10.20	25.0	3
86	*Saurauia* sp	2				6.60	7.0	3
87	*Sambucus javanicus*	1				2.00	1.5	3
88	*Trewia ambigua* (batobato)	3				5.00	7.0	3
89	*Callicarpa erioclona*	1				2.10	1.0	[b]4
90	*Clerodendron quadriloculare*	1				3.70	2.0	4
91	*Tabernaemontana pandacaqui* (pandacaqui)	3				4.50	5.5	4
92	*Wikstroemia meyeniana*	1				2.08	1.5	4
	Total	353	76.35	19.08	57.27			

[a] The volume of trees less than 10 centimeters in diameter is omitted.
[b] This story is regarded as part of the undergrowth.

As may be seen from Table XII, dipterocarp species form a noticeable part of the stand, but the forest is still very complex and the percentage of dipterocarp timber by volume is low.

The dipterocarps at these elevations are relatively small, rarely

reaching a height of more than from 35 to 40 meters. The main canopy is not only low, but it is also very open, so that both the lower stories and undergrowth are well developed.

The original forest on the lower slope of the mountain must certainly have been more distinctively dipterocarp than is the forest which we now find in a virgin condition at and above 400 meters in elevation. The management problem presented by the forest is the same as that presented everywhere throughout the Islands by forests which are located within easy reach of a large agricultural population. Such forests are always drained of their more valuable species throughout a long period of years until the species most sought after disappear; after this the edges of the forest pass through a period of extremely heavy culling, which leaves them in an almost hopeless condition. The edges of the Maquiling forest will certainly not return to their original composition and volume in any reasonable period, without the aid of actual reforestation. The complete closure of such areas as have been most heavily cut over will result in the gradual entrance of dipterocarp species, but at the same time many other species of less desirable character will gain the ascendency and the forest will necessarily pass through a period of, perhaps, from two hundred to three hundred years during which dipterocarps will remain inconspicuous elements. That portion of the forest lying a little farther to the interior in which dipterocarp seedlings and saplings are fairly well represented will return to its original composition and volume in a much shorter period of time and without actual reforestation. The problem presented is that of removing a considerable portion of what is at present the dominant story, and of removing it in such a manner that the dipterocarp element in the forest will have a chance to develop at least as rapidly as the other components. Were there any market for the trees which make up the bulk of the present canopy, the matter of making the necessary opening would be very easily handled. For the most part, however, the species which make up this canopy have no market whatever, and unless a market could be developed for them the only possible way of giving the dipterocarps and other valuable species an equal chance in the present mixture would be by girdling and cleaning operations, which would necessarily be conducted at a very high cost.

PLANT ASSOCIATIONS ON CLEARED LANDS

Land which has been cleared of forest usually passes over either to second-growth forest or to grassland.

If the land is cleared of forest and not cultivated, it is very quickly covered by second-growth trees. The most prominent are *Trema amboinensis* (anabion), *Homalanthus populneus* (balanti), *Macaranga bicolor* (hamindang), *Macaranga tanarius* (binunga), *Mallotus ricinoides* (hinlaumo), and *Mallotus moluccanus* (alim). One of these, particularly one of the first four, may in certain localities form almost pure stands. Thus, a small cleared plot at an elevation of 450 meters on Mount Maquiling was very quickly covered by a growth consisting almost entirely of *Trema amboinensis,* while cleared areas on Mount Mariveles at a similar elevation frequently show practically nothing but *Homalanthus populneus.* Along with the trees mentioned there may be a number of others, but they usually occur in much less abundance. All of these trees are small, soft-wooded, rapidly growing species. They reach maturity early, are subject to decay and insect attack, and thus are very short lived.

The future development of these second-growth forests varies with their size and situation. If the second-growth forest is a small patch in a dipterocarp forest or is on an area adjacent to one, some of the species of the dipterocarp forest will invade the second growth. The first invaders are frequently species of the genus *Canarium* or of the families Meliaceae and Sterculiaceae. The second-growth trees are very intolerant of shade and form only a very light canopy. The conditions under this canopy are very dry as compared with those in the original forest, and especially in regions with a pronounced dry season are apparently not favorable to species requiring the moist conditions of a dense forest. The stages through which the forest passes in returning to the original dipterocarp type have not been studied, but the changes must be extremely complex and the time required considerable, for as will be shown later, the trees of dipterocarp forests, unlike those of the second growth, usually develop in dense shade and are very slow growing.

The second-growth forest will apparently give place to a dipterocarp one much quicker in a region without a pronounced dry season than in one which has a long season of dry weather. Where the dry season is not pronounced, dipterocarps, if there are seed trees present, may seed into the second growth very quickly, and in many cases the seedlings will be able to survive. Climbing bamboos and other vines frequently come into the second-growth forests to such an extent that they form a very dense tangle through which it is difficult to pass.

If the second-growth forest is widely separated from any dipterocarp forest, it is not likely to become dipterocarp in character. The first trees, which are very intolerant of shade, gradually give way to other more tolerant species, and the composition of the forest becomes more complex. The trees are still mostly small, soft-wooded species and of little or no value in the production of timber. It is thus evident that little can be expected from these forests until they have been planted with more valuable species or until a neighboring dipterocarp forest has spread to them.

So far we have considered only land which has been cleared and not cultivated. In the past, however, almost all clearing has been for the purpose of cultivation. The succession of vegetation naturally varies greatly with the subsequent treatment, and results in the production of either grassland or second-growth forest.

The most primitive method of cultivation, and one which is practiced even now by some of the wild tribes, is to make a small clearing, or "caiñgin," in the midst of the forest, plant it to rice or yams for a year or two, and then, as weeds grow, to abandon it. These small patches are quickly covered by second-growth trees which kill out the weeds.

A more destructive system and one which has been very generally practiced is the making of clearings on the edge of the forest. These clearings are cultivated by very primitive methods. Cogon grass (*Imperata exaltata*) or talahib (*Saccharum spontaneum*) comes in along with various herbaceous annual weeds, conspicuous among which are species of composites. The area is burned over regularly, which results in the death of practically all tree species and the spread of the grass, as the large underground rhizomes of the latter are not injured by fire. In a few years the grass takes possession of the area and cultivation is abandoned, as it is easier to clear a new patch of forest than to eradicate the grass by the primitive methods of cultivation generally in use.

It is at this point that the differences in climate probably play their most important rôle in determining whether the land shall remain permanently in grass or return to forest. In regions with a pronounced dry season the dead leaves of the grass become, in the dry weather, very inflammable. These grass areas are burned over regularly. Tree seedlings are thus killed, and the area remains permanently in grass. This shifting system of cultivation has resulted in producing and extend-

ing grasslands until at the present time their extent is, according to Whitford,[20] four times as great as that of cultivated lands.

In regions without a pronounced dry season the grass does not become so readily inflammable and the trees have a chance to become established. This point has been discussed in connection with the distribution of forests in the Philippines.

Imperata exaltata is rarely more than 1.5 meters in height, while *Saccharum spontaneum* is frequently more than 3 meters. The latter grass grows in more moist situations than does *Imperata exaltata* and forms denser stands. Growing along with the grasses and particularly with *Imperata* are a few other plants. Their total bulk is small, and they are usually characterized by having large underground structures which are not injured by fire.

There are a few trees which are able to grow up through the grass, even when this is burned over regularly, provided the burnings do not occur at too frequent intervals. Notable examples are *Bauhinia malabarica* (alibangbang), *Antidesma ghaesembilla* (binayuyu), and *Acacia farnesiana* (aroma). These trees have well-developed roots, and sprout readily from the base of the stem after the upper portion has been killed. After each succeeding fire a larger stem is produced, until finally the tree is able to shade out the grass around it to some extent and may form the center of a small clump. These trees, however, occur in grass regions, which are regularly burned, only as scattered individuals or small clumps, as they can make but little headway against the grass when subjected to fire.

Second-growth trees grow up and kill the grasses by shading when the latter are not burned. This process generally requires only a few years, as the trees to furnish seed are usually scattered throughout the grass areas, especially in ravines and along the banks of streams. The seeds are usually small and are readily dispersed by birds or by the wind, and nearly all of the second-growth species grow very rapidly. The first stages in the invasion by tree species differ greatly from those on cleared land. The first species present are naturally those fire-resisting ones which are usually present in grass areas. However, many other species come in quickly, among which there are usually individuals of the same species that invade cleared areas. The chief difference between the first stages of second-growth forest in grass areas and on cleared land is that on

[20] *Bull. P. I. Bur. of Forestry* (1911), No. 10.

grasslands there is usually a greater diversity of tree species than on cleared lands.

As the second-growth forest increases in age it becomes denser, owing to the fact that the trees which grow up in it are likely to be more tolerant of shade than some of those forming the first stand. If the forest is not situated near a dipterocarp one, it will continue to be composed of small trees of little or no value in the production of lumber and only a small proportion of which will make even good firewood.

Despite the fact that the trees of the second-growth forest are not valuable, the growth of such a forest on grasslands is a decided practical advantage. The tall grasses of the grass areas are coarse, and do not make good forage for animals. They serve as feeding grounds for swarms of locusts, which every year do great damage to cultivated crops, particularly rice, sugar cane, and corn. The soil of grasslands, moreover, is very unproductive, while it is much easier to put under cultivation land in second-growth forest than that covered by grass, as the roots of the latter are exterminated only with great difficulty.

From a consideration of grasslands and second-growth forest it is evident that if a dipterocarp area is to be kept as such, it must either be logged in such a manner that the forest is not destroyed or the area subsequently must be replanted. Both of these methods will be discussed later. If the influence of man were removed from the Archipelago, the grass areas would grow up into second-growth forests and the dipterocarp forests would gradually, in the course of centuries, occupy most of these areas. However, this fact is of little importance from the standpoint of practical forestry, as the time required would be many centuries.

The development of second-growth forests is, with the same treatment, remarkably uniform over the entire Archipelago. There are, however, certain minor variations. It seems wise at this point to describe briefly the successions on the cut-over areas of three of the forests already described, as illustrating different courses of development under different conditions. These results will be of interest later in connection with the problem of management.

CUT-OVER REGION IN NORTHERN NEGROS

A lumber company has been operating for a number of years in the forest previously described as occurring on the banks of Himugan River in northern Negros. Trees under 50 centi-

meters in diameter are not cut, but as already pointed out the great bulk of timber is contained in the massive trees of the dominant story. The cutting of the large trees results, therefore, in the breaking and killing of a large proportion of the smaller ones. The ground is opened up to such an extent that almost all seedlings are killed by insolation, while most of the small trees become unhealthy and finally die. All of the large defective trees which have been left have been killed by brush fires, except in the very recent cutting areas. The ground is thus practically cleared of its original vegetation, and is very quickly covered by a second-growth forest.

The first plant to become established is a species of wild banana. This occurs abundantly on waste lands and in forests from which trees have been removed. The fruits are eaten by birds, and the seeds are thus quickly scattered. It is frequently abundant in cut-over areas even before the logs have been removed. Some small herbaceous weeds enter the area, but they are few in number and apparently have little or no effect on the succession of vegetation. Small patches of *Panicum sarmentosum* are sometimes conspicuous, particularly on the perpendicular sides of the cuts made for the railroad. The banana is quickly followed by tree species, which soon cover the ground except where the banana has formed small patches which shade the ground and keep out the trees. *Trema amboinensis* (anabion) is by far the most prominent tree in the second-growth forest, and in places it forms practically pure stands (Plate IX, fig. 2). Along with it are several other species, the most prominent being *Mallotus moluccanus* (alim), *Homalanthus populneus* (balanti), *Macaranga bicolor* (hamindang), *Macaranga tanarius* (binunga), and *Pipturus arborescens* (dalonot). The canopy here, as in all such second-growth forests, is very light and the conditions under it much drier than in the original dipterocarp forest.

The later stages in the vegetation were not observed, as the land is very valuable for agriculture and is quickly homesteaded and put under cultivation. It is evident, however, that the original forest is completely destroyed by the method of logging in use and that it is replaced by a worthless one of an entirely different type.

It is also evident that destroying the forest does not produce grasslands even though the brush left from the fallen trees is burned. Grass, however, covers large areas in this region, and this growth is evidently the result of a shifting system of cultivation.

The wild banana mentioned is found over large areas in Negros, but is not generally distributed over the Philippines. This general type of second-growth forest is otherwise similar to that in cut-over areas in most of the Archipelago, although as previously pointed out the specific composition may vary.

CLEARED AREAS IN BATAAN

In the forest, previously described, in Bataan back of Limay, a lumber company has been operating for the last five years and has cut a strip 15 kilometers long, running from an elevation of about 50 meters to approximately 500 meters. An exact determination of the successions is rendered difficult by the fact that each year's cutting occurred at a successively higher level and that the first stages have been observed only in the recently cut areas.

The trees of the dominant story of the dipterocarp forest are not as large as those in Negros, and there is a greater number of small trees.

Until recently the cutting has been done with a lower diameter limit of 40 centimeters, allowing the removal of all large trees. A large proportion of the small ones were, at the same time, killed by the falling of the cut trees. As in the cut-over region in Negros, nearly all seedlings were killed by insolation and most of the small trees became unhealthy and soon died (Plate X, fig. 1). The few remaining ones seem to stand small chance of reaching maturity. Still further destruction has been caused by the burning of the branches and leaves of the fallen trees over large areas. This results in the death of all trees in the burned area.

Of the original forest, only a very few scattered specimens of old defective trees and a few small unhealthy ones are left. After the trees of the original forest have been removed, the ground is quickly covered by seedlings of second-growth trees (Plate X, fig. 2). A few herbaceous weeds enter the area, but only two are prominent; namely, *Panicum sarmentosum*, which as in Negros forms small patches particularly on the steep sides of the railroad cuts, and *Blumea balsamifera* (sambong), which is especially abundant in burned-over areas. Both of these species are comparatively small, and apparently have but little effect on the further development of the vegetation.

The principal tree species is *Homalanthus populneus* (balanti or banalo), which forms practically pure stands over much of the area. Along with it are a number of other species, the chief ones being *Trema amboinensis* (anabion), *Macaranga*

bicolor (hamindang), *Macaranga tanarius* (binunga), *Mallotus ricinoides* (hinlaumo), *Mallotus moluccanus* (alim), and *Ficus variegata* (tangisang biawak). Up to this point the general type of the vegetation on the cleared land in Bataan is very similar to what has been described in Negros, although the specific composition is different, and the wild bananas are lacking in Bataan. However, in Bataan this type is practically restricted to the cutting area of the previous year, and disappears in some of the older portions of this area. The areas which have been logged for more than a year are all dominated by an erect species of bamboo (*Schizostachyum mucronatum*) known locally as *boho* (Plate XI, fig. 2). Owing to heavy cutting or clearings, this bamboo was scattered through the earlier cutting areas before the company commenced its logging operations, and as the original forest has been removed the bamboo has taken its place. The flowering habits of this bamboo are not known, but it probably spreads rapidly by means of underground stems. When it enters an area where there are small second-growth trees, it grows faster than they do and thus kills most of them by shading (Plate XI, fig. 1.) This is particularly true of *Homalanthus populneus*, which is a very small tree. This tree is very scarce where the boho occurs, while *Trema amboinensis*, a somewhat larger species, is relatively much more abundant. Thus, mixed with the boho there are patches of second-growth trees, old trees left from the original forest, and also rather extensive patches of climbing bamboo. It is possible that, as logging continues, the cutting area may be moved away from the bamboo so fast that the latter will not be able to keep up with it and that a second-growth forest will finally have a chance to develop. If, however, the boho should seed, it could readily enter the freshly cut-over areas and thus continue to dominate all of the ground. As higher elevations are reached it may be that boho will not be able to stand the environmental conditions.

Most of the boho on the cutting areas is still immature, but nearer the beach there are large forests of it which apparently are practically mature. Here it occurs in large clumps from 3 to 4 meters apart and from 12 to 15 meters high (Plate XII). Scattered in with this are dicotyledonous trees, but practically no seedlings.

In situations similar to those on which the forests of boho occur, there are also extensive areas of second-growth forest. From what has been observed in the recently cut-over areas, it would seem that when there is a competition between the boho and second-growth trees the latter largely disappear.

These second-growth forests must, therefore, have developed when the boho could not enter the area. Such a condition is easily imagined, as the ground might have been cleared during a period when the boho was not seeding and at such a distance from the latter that there was a forest barrier between them. It is also possible that the boho did not have sufficient time to grow into the area before the second-growth forest had already developed.

Whitford[21] has described the mature bamboo forest in considerable detail. He regarded it as a climax association, and believed that its composition would remain the same as at present, unless some of the constituents were artificially removed. The bamboo forest when once developed certainly seems to be very stable. It produces a dense enough shade to prevent the development of second-growth trees, while the conditions within it are apparently not favorable for the growth of shade-enduring species. It is evident that when the bamboo can enter a cut-over area it will replace the original dipterocarp forest, and it is probable that all of the bamboo forests in the Bataan region as well as in other parts of the Philippines originated as the result of clearing off the original vegetation. Since the forests of boho are second growth in character, it seems probable that in the course of time they would be replaced by the original dipterocarp type if the influence of man were removed. The stages by which this would take place are not evident, but since there is little chance of trees seeding in the boho forest to any great extent this process would, probably, take several centuries. From the standpoint of practical forestry it may be said that in the area here described the dipterocarp forest has been completely and permanently destroyed.

Boho occurs in cut-over regions throughout Bataan, and plays an important part in the vegetation of such areas, although, as pointed out, forests of second-growth trees may be developed under certain conditions. The boho is of more value commercially than the tree species. It is a thin-walled bamboo, the stems of which are split, flattened, and woven into a kind of matting, known locally as *sawale,* which is much used for walls of dwellings. It also offers possibilities in the manufacture of paper.[21a]

Seedlings of *Pentacme contorta* are springing up and surviv-

[21] *This Journal* (1906), 1, 384.

[21a] Richmond, G. R., Philippine fibers and fibrous substances: their suitability for paper making (part II), *This Journal* (1906), 1, 1075–1085.

ing in the area covered by *Homalanthus populneus*, and so it would seem that *Homalanthus*, if not destroyed by boho, would make a good nurse crop for *Pentacme*. Other species also may be able to survive under *Homalanthus*, but this point has not been determined. The success of *Pentacme* is probably connected with the moist conditions at the high altitude at which the logging is now being done.

CLEARED LAND AT THE BASE OF MOUNT MAQUILING

The two cases of second growth which we have described occurred on cleared land which had not been cultivated. The area to be considered now has been in grass as the result of cultivation. All of the land around the base of Mount Maquiling has been cleared of the original forest and put under cultivation. Much of it has subsequently grown up in grass, and cultivation has been abandoned. The College of Agriculture was established in 1909 on such an area on the northeastern side of the mountain. Between the college buildings and the mountain there were extensive grass areas. The region under consideration consists of broad flat ridges about 75 meters in altitude and separated by narrow valleys. The original forest remained, but in a very badly cut-over condition, in the valley of Molauin River.

Before the establishment of the college most of the area appears to have been burned over very frequently, and large portions of it were burned as late as 1911. Since then fires have been largely excluded, and the area is rapidly going over into second-growth forest.

As long as any area continued to be burned over, tree seedlings were killed and the area remained in grass. The grass consisted mostly of two species, *Imperata exaltata* (cogon) and *Saccharum spontaneum* (talahib). *Imperata* appears to be disseminated quicker than *Saccharum*, and at first probably occupied the larger part of the area. At present it occupies all of the driest spots, but is apparently giving way to *Saccharum* in the more favorable localities. Table XIII gives a good idea of the average composition of an area dominated by *Imperata*.

Table XIII shows that there are many herbs and shrubs present with *Imperata*, but that they are all small plants. With the exception of *Eulophia*, which has large underground roots, all of the plants have come in since the last fire and have not had time to reach their normal size. The vines are likewise recent arrivals. The presence of the large number of small miscellaneous plants shows clearly that if fire is excluded from the area, plants other than *Imperata* will become prominent very quickly.

TABLE XIII.—*Composition of plot of Imperata exaltata. Plot, 2 meters square.*

IMPERATA EXALTATA (COGON). Height, 130 to 140 centimeters.

Plants with:	
One stalk	1,675
Two stalks	147
Three stalks	82
Four stalks	38
Five stalks	19
Six stalks	15
Total plants	1,976
Total stalks	2,552

MISCELLANEOUS SPECIES.

Species.	Total plants.	Greatest height.	Average height.	Seedlings.
Herbs and shrubs:		*cm.*	*cm.*	
Eulophia exaltata	5	60	35	1
Biophytum sensitivum	7	4	3	2
Selaginella belangeri	16	3	2	
Mimosa pudica	68	18	1.5	43
Desmodium pulchellum	122	27	21	84
Commelina nudiflora	7	4.5	3	7
Compositæ	23	6	4	23
Synedrella nodiflora	10	21	8	8
Sida javensis	1	5.5	5.5	1
Riccia sp	many			
Vines:				
Streptocaulon baumii	2	6	5.5	2
Operculina turpethum	1	9	9	
Merremia umbellata	2	280	145	1
Merremia hastata	5	6	3	5
Cissus trifolia	2	173	60	
Ipomea triloba	9	69	31	4
Total	281			181

In the grass area there were a few individuals of fire-resisting trees, chiefly *Antidesma ghaesembilla* (binayuyu), *Bauhinia malabarica* (alibangbang), and *Acacia farnesiana* (aroma). Soon after fires were excluded from the region, a growth of tree seedlings, herbaceous shrubs, and vines entered quickly. The early stages of this process are accompanied by changes in the composition of the grasses, as cogon and talahib are usually replaced by species forming even taller stands, which, however, are much less dense. The grass gradually dies as the trees begin to shade it. In this manner large parts of the area have passed from grasslands to second-growth forest since 1911. The tree species which have come in are so numerous and the composition of the forest so varied that it is difficult to tell which are the most prominent species, but among them are *Melochia*

umbellata (labayo), *Columbia serratifolia* (anilao), *Litsea glutinosa* (puso-puso), *Macaranga tanarius* (binunga), *Premna cumingiana* (maguile), *Ficus nota* (tibig), *Ficus hauili* (hauili), *Mallotus philippensis* (banato), and *Alstonia scholaris* (dita). It is uncertain how long it will take this forest to occupy the whole area, but it seems likely that if fires are excluded this will take place in less than ten years. It will be seen from this that it would be a very simple matter to replace grass with second-growth forest if the inhabitants could be prevented from setting fire to the grass.

VOLUME OF DIPTEROCARP FORESTS

Whitford,[22] writing on the composition and volume of the dipterocarp forest in the Philippines, has shown very clearly that in situations suitable for the best development of species of the family Dipterocarpaceae the forest which is developed is one in which dipterocarps are the leading species not only from the standpoint of the botanist, but also from the standpoint of the forester and lumberman. He comes to the conclusion that "success in virgin forest growth should be measured in terms of bulk, or of bulk and annual increment combined;" and, again, "if measured in bulk alone, some temperate regions as compared with the Philippines show greater success in forest growth." Success in virgin forest growth may be measured in terms of bulk and annual increment combined, but a virgin forest of great bulk may be in a very poor condition for management, and bulk alone is not always a true measure of what the forest site is capable of producing.

As Whitford states, when using bulk alone as a measure of success in forest growth, we find that in temperate regions some forests, such as the coniferous ones of northwestern United States, are more successful in this respect than any forest that has thus far been accurately measured in the tropics. Unfortunately, there are not available in the Philippines any detailed stand tables of virgin hardwood forest in temperate regions for comparison with a similar table compiled from data collected in the Philippines. However, the yield tables compiled by Wimmenauer [23] for pure stands of oak in central Germany will serve as a standard for forest growth in the temperate zone. As a basis for comparison of volume and distribution of volume by

[22] Whitford, H. N., Studies in the vegetation of the Philippines, *This Journal, Sec. C* (1909), 4, 699.

[23] Schlich's manual of forestry, 3d ed., London (1905), 3, 346, 347.

diameter between forests in the Philippines and those of the temperate regions, Wimmenauer's table for oak on site I is presented here in the form of a model all-aged managed forest for 1 hectare (Table XIV). There are 16 age classes in the original table, the oldest being 160 years. The basal areas and volumes for each age class have been determined by dividing the volume and basal areas of an average stand of that age for 1 hectare by 16, so that there are represented that number of distinct age classes in our table for 1 hectare. That is, the volume and basal area given in Wimmenauer's table for the 160-year class divided by 16 give the volume of that class in an all-aged managed forest having represented in it trees of all ages from 10 to 160 years. Likewise, the volume given in the original table for an even-aged forest of 150 years divided by 16 gives the representation of that class in an all-aged managed forest of 1 hectare and so on down to the youngest class repre-

TABLE XIV.—*Oak. Site I. Europe. Model all-aged forest of 1 hectare.*

Age in years.	Diameter.	Basal area.	Volume.	Age in years.	Diameter.	Basal area.	Volume.
	cm.	*sq. m.*	*cu. m.*		*cm.*	*sq. m.*	*cu. m.*
10	2.54	0.573		100	39.40	2.137	34.12
20	6.10	1.004	2.45	110	42.90	2.194	36.39
30	10.90	1.276	7.43	120	46.70	2.252	38.43
40	15.50	1.477	12.81	130	49.80	2.295	40.31
50	20.80	1.649	17.49	140	53.30	2.335	42.06
60	25.10	1.793	21.69	150	56.60	2.381	43.77
70	29.00	1.908	25.32	160	59.70	2.410	45.43
80	32.50	2.008	28.55	Total		29.774	427.82
90	36.10	2.079	31.57				

sented—that of 10 years. The table which we have thus computed for oak represents an average of even-aged managed stands in which all ages occupy equal areas. Comparing this table with that for one of our best dipterocarp forests, that of northern Negros (Table XV), we see that in regard to volume and basal area the two forests are not greatly dissimilar. Judging from the standpoint of bulk alone, the virgin forest in the Philippines seems to be somewhat more successful than a normal managed forest, containing all ages, in the temperate zone.

Although the total volume of the dipterocarp forest exceeds that of the managed oak forest by 92 cubic meters, it will be seen at a glance that the volume of the Negros forest is distributed throughout diameter classes up to 170 centimeters, while the largest diameter class in the managed forest is 60 centimeters. The conclusion that must be drawn from this is that unless the dipterocarp trees produce, in the same length

TABLE XV.—*Dipterocarps. Site I. Philippines. One hectare of virgin forest in Negros.*

Diameter in centimeters.	Basal area.	Volume.	Diameter in centimeters.	Basal area.	Volume.
	sq. m.	*cu. m.*		*sq. m.*	*cu. m.*
15	0.421	1.02	105	2.198	33.87
25	1.423	7.25	110	1.664	26.26
35	1.539	9.53	115	1.400	21.61
40	1.517	15.81	120	2.067	29.25
45	1.715	18.57	125	1.277	21.17
50	1.570	17.37	130	1.308	21.80
55	1.442	16.67	135	1.222	20.79
60	1.603	19.21	140	1.336	23.23
65	1.825	23.31	145	0.672	8.87
70	1.581	20.28	150	0.770	11.18
75	1.683	22.18	155	0.245	4.30
80	1.779	24.48	160	0.591	9.72
85	1.818	25.78	165		
90	1.466	21.14	170	0.248	3.16
95	1.301	19.02	Grand total	39.251	519.58
100	1.570	22.75			

of time, diameters about twice as great as those of the oak trees, this Negros forest is not in any way as successful in regard to growth. As will be shown later in discussing rates of growth, it is very evident that no such increased rate of growth in virgin stands in the Philippines can be expected. Such being the case, it is equally obvious that, taking our curve for the oak forest of Germany as normal, our dipterocarp forest in Negros is both extra normal and overmature; that is, it is probable that we have in our largest virgin forest of the Philippines both an overstocked and an overmature condition.

The dipterocarp forest under discussion here is a type of the best forest produced in the Philippines in regard to both simplicity of composition and volume per hectare. It approaches as nearly what the lumberman desires in forest growth as can be expected of any virgin forest in the Philippines, but from the standpoint of forest management, although the forester is interested in the production of a large volume per hectare, it cannot be said to be as satisfactory. From this standpoint the first defect to be noted is that of excessive overmaturity. Accompanying this is the fact that we have our volume distributed with fair regularity through a large number of diameter classes without the representation in the smaller diameter classes necessary for the successful reproduction of the forest under any system of management, which takes into consideration the problems of utilization and the excessively rapid reproduction

of undesirable weeds when a great amount of light is admitted to the forest floor.

Another condition which is appreciated as a defect both by foresters and lumbermen is that the apparently very heavy stand per hectare is often reduced in amount by excessive heart rot. More or less defect always accompanies the development of dipterocarp timber to a large size, and in the forest of northern Negros where the bulk of the stand is in an overmature condition heart rot sometimes reduces the volume by as much as 35 per cent. The presence of this defect in the stand of timber can always be detected, but there is no possibility of determining its amount, except within very wide limits. As a general proposition it is true that the heavier the stand of timber the greater will be the percentage of defect.

Passing now to a consideration of other dipterocarp forests in the Philippines, namely, those of Bataan and northern Laguna Provinces, we find that here the forest falls far below the standard as represented by the managed forest of Germany. Stand tables for forests of these two regions are given on pages 433 and 438. Taking the forest of northern Laguna as an example, we see that we have neither the same excessive overmaturity that we have in the Negros forest nor the great bulk. From the standpoint of the lumbermen the latter fact is a very decided defect. However, looking at the forest from the standpoint of the man who is to manage and reproduce it, this forest presents a much easier problem than does that of Negros, in as much as the total volume is distributed through a smaller number of diameter classes and the bulk of the volume lies in the intermediate size classes. The same statement may be made with reference to the forest of Bataan, where the distribution by diameter classes shows a distinct concentration of volume at diameters of from 40 to 60 centimeters.

Whitford [24] emphasizes the fact that the best of our dipterocarp forests approach purity of stand, when bulk alone is considered. He also brings out the fact that, if bulk is disregarded and the number of species taken as the criterion, the family Dipterocarpaceae is by no means so evident, as many species of smaller trees are always present. From the standpoint of the lumberman who desires to remove only the merchantable portion of the stand, the presence of these small species is of little importance. However, from the standpoint of the forester it demands consideration. The dipterocarp forest contains many

[24] *This Journal, Sec. C* (1909), 4, 699.

times the number of species found in hardwood forest areas of equal size in the temperate zone, the number of species being frequently fifteen or twenty times as great on an equal area in the Philippines. In the temperate regions an excessively overmature forest does not present a very serious management problem. In the first place, the forests of temperate zones do not have an understory of a vast number of miscellaneous species standing ready to claim the area as soon as the dominant class is removed, and, secondly, seeds and seedlings of the most important species in temperate regions are able to establish themselves at once on the area from which the overmature timber alone is removed, without having to enter into competition with numerous weed species which do not normally exist in the area. In the Philippines, however, both of the above conditions obtain, and the result of removing the main portion of any tract of forest has already been very fully discussed.

It becomes evident from the above discussion that as a measure of success from the standpoint of management neither bulk nor perhaps even bulk and increment combined can be used without taking into equal consideration the distribution of bulk throughout the different size classes. The conclusion to which we are forced is that in the Philippines where we have a dipterocarp forest of exceptionally high volume per hectare we have at the same time an unsatisfactory distribution of this volume. It also becomes apparent, that as a measure for successful forest management volume taken together with equal-size distribution is a more satisfactory measure than either volume alone or volume and increment combined.

GROWTH

GENERAL DISCUSSION AND METHODS OF MEASUREMENTS

Temperature in the tropics throughout the year is uniform and favorable for growth, and it has been generally believed that the growth of tropical plants must be very rapid. This is undoubtedly true for most plants growing in the open. A striking example which is often quoted is that of the bamboo which has been known to exceed 50 centimeters per day in its period of most rapid growth. It should be remembered, however, that in this case almost the entire growth for a whole year is made in a few weeks, while food is manufactured during the entire year. The growth of tropical plants is usually distributed throughout the year, and the high annual rate of growth, in the open, is due to the long season in which growth is possible rather than to particularly favorable conditions at

any given time. When we come to consider the growth of plants in a forest we find conditions quite different, owing to the density of the vegetation, and it is doubtful if any of the plants, except possibly some of the largest trees, are under exceptionally favorable conditions at any time. It should not surprise us, therefore, that forest trees show relatively slow rates of growth.

Great difficulty is encountered in any attempt to estimate the age of forest trees in the Philippines. In no case has it been demonstrated that annual growth rings are present. An effort has been made in this paper to determine the probable age and rates of growth of some of the most important commercial species by using the rates of growth on large numbers of individual trees for a period of one or a few years. It is evident that the results obtained cannot be absolutely accurate, but owing to the large number of different size classes employed it is believed that the results will give a fair indication of the rates of growth of trees in a virgin forest.

The growth data presented in this paper are the results of two series of measurements. One series, including all the growth data from the forest of northern Laguna and Mount Maquiling, consists of very careful measurements made at intervals of from one to three months for a period of one year. The trees were measured at breast height in every instance, except where buttresses made measurement at a higher point unavoidable. The results are presented in the form of diameter growth, but the measurements were taken with a steel tape and were, of course, originally girth measurements. In order to be certain that the measurements were taken at the same point each time, shingle nails were driven into the trees, for a short distance, just below the tape, at the time of the first measurement. In only a very few instances did the nails cause the production of swellings, and such cases were discarded.

The growth data for trees in Bataan Province are based on 2 measurements taken at an interval of either eight or nine years. The trees are located in 4 different places at varying elevations in the Lamao forest reserve. They were selected and measured by officers of the Bureau of Forestry in 1905 or 1906. All of the measurements, with the exception of those on type area C at an elevation of 700 meters, were made in 1906 by Forester W. M. Maule, with a steel tape 1.37 meters (4.5 feet) above the ground and at a point 1 meter above a notch cut in the trunk of the tree. Those on type area C were first measured in 1905 with calipers, 2 measurements being taken, the first

north and south and the second east and west; the average of the 2 measurements was taken as the correct reading. The second measurements were made by us in March, 1914, with the assistance of F. W. Foxworthy and D. D. Wood. These measurements were all made with a steel tape. In some few instances it was not possible to locate the exact point at which the first measurement was taken, but where this was the case and where there was sufficient irregularity in the bole of the tree to make the data unreliable the measurement was discarded.

In the first series of measurements the data collected are known to be accurate for the year in question. There are presented in this paper climatic data for the period covered by the measurements, and from a comparison of these data with those for the Islands as a whole for the last ten years it appears that the year 1913 to 1914 does not depart markedly from the normal with respect to climatic factors. The greatest number of measurements for any one species were those for *Parashorea plicata* on Mount Maquiling. A second yearly record of the growth of this species was taken in January, 1915. According to these figures the age of a tree 70 centimeters in diameter differed from the age calculated in this paper by only 1.4 per cent. This indicates that the rates of growth shown by the measurements in the first series are very close to the average yearly rates of the species measured. In the second series of measurements the period covered is so long that any inaccuracies arising from the periodic variations of climatic factors may be considered negligible.

The original figures as collected were in the form of measurements of size and growth in terms of centimeters of girth. The first steps in the reduction of these figures to usable form were their reduction to diameter figures, with the growth reduced to a period of one year, on the assumption that the girth was a circle. These figures were then grouped by species and diameter classes of 5 or 10 centimeters, and tables were prepared showing the growth of each tree of any one species or group of species for the period of one year and the total and average growth of all the trees in each diameter class. Whenever sufficient data for one species were at hand, a table for that species, independent of all others, was prepared. In most instances, however, this was not possible with the figures from Bataan, and in order to group the data into usable form the following classification of species was adopted: All of the species under consideration were grouped into 4 classes. Class I includes all species, such as the dipterocarps, which at maturity

occupy a dominant situation in the forest. Class II includes all those which at maturity are subdominant; that is, which even when fully developed have their crowns overtopped by the trees of Class I, but which are still considered to be in the dominant story. Class III includes those species which at maturity have their crowns spread at a considerable distance below the main canopy and belong in the second story. They are distinctly tolerant of shade throughout life. Class IV comprises the remainder of the plants of tree habit in the forest, which ordinarily do not become much over 10 or 12 meters in height. These constitute the third story. Tables for each of the above tree classes were prepared similar in form to the tables previously constructed for individual species. These tables show the annual rate of growth, for each 10-centimeter class, of trees which occupy practically identical situations in the forest.

The average rate of growth of each class can be taken to represent the rate of growth of that class in the forest. In order to approximate the total ages of trees of different sizes in the forest, the average annual rate of growth of each 10-centimeter class was divided into 10 centimeters and the quotients assumed to be the number of years necessary for the species or group of species in question to pass through a 10-centimeter diameter class. Summing up these quotients for the smaller sizes, we obtain a figure which represents the age of our species or group of species for any 10-centimeter size class; that is, the quotient obtained by dividing the annual growth of the size class from 1 to 10 centimeters into 10 centimeters may be assumed to be the age of a 10-centimeter tree. Adding this quotient to the quotient obtained in a similar manner for the 10- to 20-centimeter class we have the age of a 20-centimeter tree. In order to obtain figures of the age of trees of any size and to present the above data in graphic form, curves of diameter growth on age were constructed by plotting this data on cross-section paper, the ordinates of the curves being diameters and the abscissæ being years. For convenience in comparing the rates of growth of various species in the Philippines with those of the temperate zone, there have been plotted, in connection with these curves, growth curves for hardwoods in the virgin forest of the central hardwood region of the United States. The data for these growth curves of temperate species are taken from Graves and Ziegler.[25]

[25] Graves, H. S., and Ziegler, E. A., The woodman's hand book, *Bull. U. S. Forestry Sur.* (1910), 36, 189–190.

ANNUAL DIAMETER GROWTH

Measurements were made on *Parashorea plicata* (bagtican-lauan) growing in the forest on Mount Maquiling at an elevation of approximately 300 meters. The stand, as previously described, is a very open one for a dipterocarp forest, and *Parashorea* develops a deep crown. As might be expected from these conditions, the figures for *Parashorea* show a more rapid rate of growth than do those for any of the other dipterocarps measured. The diameter growth from January 13, 1913, to January

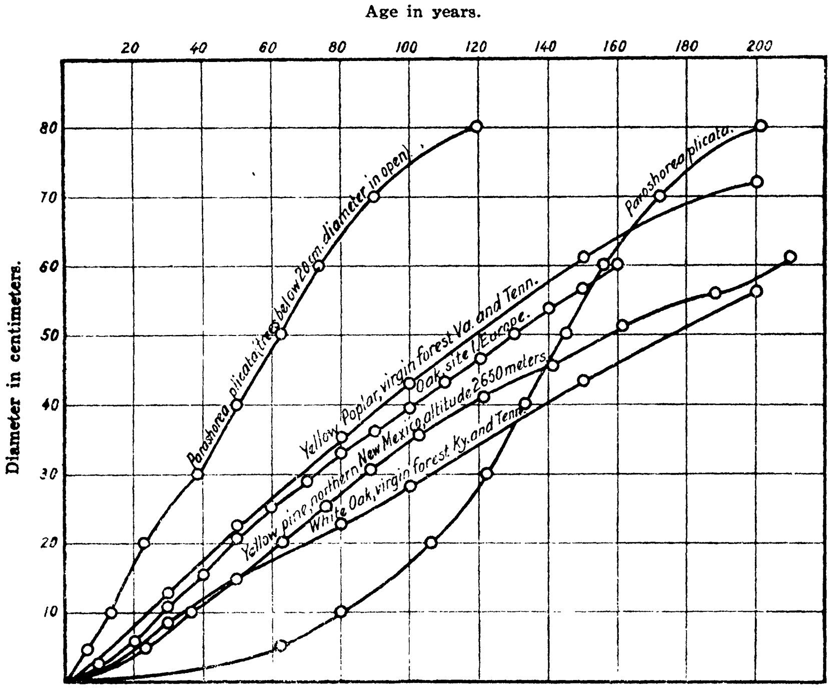


FIG. 1. Rates of growth of *Parashorea plicata* in forest and open.

13, 1914, for all of the trees measured in the forest is given in Table XVI. These results are plotted as one of the curves in fig. 1 in a form to show the age of trees of any diameter. Perhaps the most remarkable point brought out by the figures and curve is the very low rate of growth shown by the small individuals of *Parashorea*. Thus, according to these figures a tree 5 centimeters in diameter is 62 years old and one 20 centimeters in diameter is 44 years older. After this, as the trees get access to the light, growth becomes much more rapid.

For comparison with *Parashorea* there are plotted in fig. 1

TABLE XVI.—*Annual diameter growth of Parashorea plicata (bagtican lauan) in virgin forest, Mount Maquiling, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	4.61		5.19	0.143	14.92	0.127
2	3.88	0.112	7.40	0.121	13.21	0.318
3	2.26		7.29	0.395	12.72	0.137
4	4.15	0.217	9.11	0.339	12.10	0.255
5	2.43	0.070	6.28	0.378	11.09	0.494
6			5.56	0.366	12.61	0.916
7			7.18	0.280	10.15	0.681
8			8.80	0.447	14.00	0.239
9			5.39	0.280	14.30	0.277
10			5.80	0.028	14.19	0.377
11					13.39	0.168
12					11.44	0.364
13					19.35	1.112
14					15.00	0.236
15					19.55	0.497
16					17.38	0.141
17					15.78	0.345
18					18.90	0.188
19					17.20	0.408
20					16.20	0.379
21					19.42	0.461
22						
23						
24						
25						
26						
27						
28						
Total		0.399		2.777		8.110
Average growth		0.080		0.279		0.397
Years in class	62.4		18.0		25.8	

No. of tree in class.	Diameter class in centimeters.					
	20 to 30.		30to 40.		40 to 50.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	20.80	0.500	30.40	0.492	42.75	0.804
2	22.65	0.620	33.00	0.318	44.10	1.110
3	22.20	0.255	34.60	1.058	43.10	0.830
4	27.50	1.045	31.65	0.506	44.25	0.455
5	29.20	0.617	33.50	0.949	43.40	0.567
6	29.95	0.445	39.60	1.047	40.90	0.600

TABLE XVI.—*Annual diameter growth of Parashorea plicata (bagtican lauan) in virgin forest, Mount Maquiling, Laguna Province, Luzon*—Contd.

No. of tree in class.	Diameter class in centimeters.					
	20 to 30.		30 to 40.		40 to 50.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
7	27.00	1.006	36.20	1.536	43.25	0.513
8	26.50	0.429	38.65	1.881	40.75	1.315
9	25.55	1.132	39.00	1.088	42.50	1.827
10	25.70	0.445	36.55	0.236	43.30	0.774
11	26.95	0.344	35.40	1.079	41.10	0.999
12	26.15	0.364	39.75	0.858	43.40	0.286
13	29.00	0.902			45.70	0.859
14	28.90	0.568			46.80	0.664
15	26.85	0.785			49.25	0.903
16	26.00	0.141			46.60	0.698
17	27.90	1.083			45.50	1.071
18	26.50	1.001			47.50	1.186
19	27.95	0.140			46.80	1.050
20					46.75	1.217
21					47.35	0.661
22					49.20	0.521
23					46.70	0.268
24					46.75	0.477
25					48.80	1.116
26					49.75	0.784
27					49.00	1.006
28					46.00	0.661
Total		11.822		11.048		23.222
Average growth		0.624		0.920		0.830
Years in class	16.0		10.8		12.0	

No. of tree in class.	Diameter class in centimeters.					
	50 to 60.		60 to 70.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	54.60	0.366	64.90	0.276	78.90	0.349
2	54.90	0.901	62.80	0.524		
3	54.50	0.593	64.50	2.140		
4	51.15	1.222	60.25	0.823		
5	59.50	0.924	60.50	0.674		
6	58.15	1.659	63.20	0.344		
7	57.90	0.532	62.70	0.478		
8			67.10	0.236		
9			67.30	0.028		
10						
11						
12						
13						
14						

TABLE XVI.—*Annual diameter growth of Parashorea plicata (bagtican lauan) in virgin forest, Mount Maquiling, Laguna Province, Luzon*—Contd.

No. of tree in class.	Diameter class in centimeters.					
	50 to 60.		60 to 70.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
Total		6.197		5.523		0.349
Average growth		0.885		0.613		0.349
Years in class	11.3		16.3		28.7	

curves of growth for oak on site I in Europe,[26] of yellow pine in northern New Mexico at an altitude of 2,700 meters,[27] and of yellow poplar and white oak in the central hardwood region of Virginia, Kentucky, and Tennessee. It will be seen from the curves that the rate of growth of white oak is faster than that of *Parashorea,* until the trees are 37.5 centimeters in diameter, while yellow poplar grows faster than *Parashorea* until it attains a diameter of 65 centimeters. Yellow pine in New Mexico and oak on site I in Europe show rates of growth intermediate between white oak and yellow poplar. It is also to be noted that the curve for *Parashorea* crosses those of all of the temperate zone species and in the larger diameter classes lies considerably above them. This shows clearly that in the latter part of the life of *Parashorea* it is distinctly the fastest growing of all the species here considered. Yellow poplar, the fastest growing of the temperate zone species, takes one hundred fifteen years to grow from 30 centimeters in diameter to 70 centimeters, while *Parashorea* makes the same growth in fifty years. The results would seem to show clearly that only the larger individuals of *Parashorea* are in a position to take advantage of the more

[26] Schlich, W., Schlich's manual of forestry, 3 ed. Bradbury Agnew and Co. Ld., London (1905), 3.

[27] From data collected by O. F. Bishop in the Carson National Forest in 1911.

favorable conditions for growth which exist in the tropics and that throughout the earlier period of their existence they maintain themselves and grow under very adverse conditions; that is, *Parashorea* in a virgin forest passes through an exceptionally long suppression period as compared with trees in a deciduous forest of the temperate zone.

In as much as climatic data collected in the forest on Mount Maquiling show that conditions are favorable for plant growth throughout the year, it seems clear that this long period of suppression must be referred largely to the lack of light under the main canopy of the forest. A study of the curves for temperate species, presented in connection with *Parashorea* in fig. 1, shows that none of these species undergoes any considerable period of suppression in youth. The curve for oak in Europe would not be expected to have this suppression period, as it represents a planted forest in which the crowns of the trees are exposed to full overhead light throughout life. The curve for yellow pine likewise shows no marked suppression period. This is connected with the fact that the tree is one of exceptional intolerance to shade, and grows normally in a very sparse, open forest. The curves for white oak and yellow poplar are taken from data collected from virgin forests in the United States which are commonly considered dense deciduous forests for temperate regions. Both of these species are rather rapid growing, and the convex form of the curves would indicate very little in the way of a suppression period due to shading. A comparison of the form of the curves for these two species with that for *Parashorea* seems to show that the density of the canopy of a deciduous forest in the temperate zone is by no means so great as is that of the dipterocarp forest of Mount Maquiling.

It has been previously pointed out that the forest of Mount Maquiling has a very open canopy as compared with the other dipterocarp forests discussed and that the rates of growth obtained for *Parashorea* are faster than those for any other dipterocarp measured. It is to be expected from this that dipterocarps in most of the forests of the Philippines will show an even greater suppression period than does *Parashorea plicata* on Mount Maquiling. This would seem to be true in the forest of Bataan (Table XXIII) where, according to the available figures, the average dipterocarp is 116 years old when 5 centimeters in diameter.

The rapid growth made by young individuals of *Parashorea* when growing in the open confirms our conclusion that the long suppression period shown by forest-grown seedlings is due to a

lack of light. At the base of Mount Maquiling on the northeastern side is a very small pure stand of *Parashorea,* in which none of the trees is more than 14 centimeters in diameter. This stand is at the edge of the forest near a large seed tree, and probably became established under a canopy which has since disappeared. The straggling individuals near the edge of the stand are in an exposed situation; they are smaller than those in the main stand, and show a slower rate of growth. While thus too great an exposure appears to be injurious to young plants of *Parashorea,* they show a much faster rate of growth in the open than in the forest, as is shown by a comparison of Table XVI with Table XVII, in which are given the rates of growth of trees in this stand in the open for the period from January 13, 1913, to January 13, 1914. The upper curve in fig. 1 is plotted to represent the age of different diameter classes of *Parashorea,* the age of classes below 20 centimeters being based on the rate of growth of the trees in the open, while the time required for trees to pass through the larger classes is taken from the table for *Parashorea* in the virgin forest. Assuming that this curve would represent approximately the age of different diameter classes of *Parashorea,* if grown in the open, we find that it takes in the open less than half the time to reach any diameter up to 65 centimeters that it does in the forest. The greatest difference is, naturally, in the smaller classes, which in the forest are most heavily shaded. Thus, a tree 20 centimeters in diameter is 23 years old if grown in the open and 106 years old if grown in the virgin forest.

The curve for *Parashorea* grown in the open shows a much more rapid rate of growth than do any of the temperate zone species which we have considered. The most rapid growing of the latter is yellow poplar, which is 183 years old when it reaches a diameter of 70 centimeters, while *Parashorea,* grown in the open, attains the same size in ninety years. These facts indicate that if foresters in the tropics were able to follow the German practice and plant solid dipterocarp forests of rapid-growing species, such as *Parashorea plicata,* they would easily surpass the results obtained in managed forests in the temperate zone. As will be shown later, however, environmental considerations make the planting of dipterocarps on any large scale an impracticable proposition, and foresters in the Philippines must, for the present at least, deal with species as they occur in virgin or partially cut-over forests. They will, therefore, have to accept as inevitable a long suppression period in all of their dipterocarp species, and cannot hope that the rate of growth

TABLE XVII.—*Annual diameter growth of Parashorea plicata (bagtican lauan) in the open, Mount Maquiling, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 15.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	4.95	0.683	7.10	1.145	10.05	0.749
2	4.17	0.595	7.60	0.605	13.60	1.130
3	4.14	0.575	6.15	0.668	13.80	0.986
4	3.60	0.988	5.15	0.975	10.95	1.260
5	3.74	0.748	6.04	0.638	10.24	0.924
6	4.29	1.590	5.39	0.810	10.88	0.955
7	3.30	0.558	6.95	0.430	11.10	0.955
8	3.43	0.334	6.10	0.381		
9	4.35	0.716	5.15	0.575		
10	4.70	0.780	5.06	0.940		
11	4.92	0.509	7.35	0.844		
12	4.87	0.702	7.37	1.161		
13			6.16	0.716		
14			5.42	0.495		
15			6.00	0.525		
16			6.40	0.732		
17			4.62	0.509		
18			5.04	0.574		
19			6.69	0.860		
20			5.75	0.765		
21			5.51	0.716		
22			5.02	1.224		
23			6.63	1.030		
24			5.90	1.260		
25			9.00	0.382		
26			9.20	1.305		
27			7.95	0.920		
28			9.30	0.844		
Total		8.778		22.029		6.959
Average		0.731		0.787		0.993
Years in class	6.85		6.33		5.00	

of even such a rapid-growing species as *Parashorea plicata* will be much greater than that of temperate zone species.

However, in comparing the results which may be expected from management in the Philippines with those that can be obtained in temperate zones, the very long period of suppression may very reasonably be left out of consideration. In other words, we may consider those individuals of the stand which lie below from 5 to 10 centimeters in diameter not as a portion of the stand, but merely as the necessary factors of reproduction which are always present in the forest. Following out this

conception and plotting the curve of growth for *Parashorea* with that portion of the curve below 5 centimeters omitted, we see that the species does not compare unfavorably with those of the temperate zone for virgin forest. Referring to fig. 8, page 496, in which curves of this character are presented, we find that the curve for bagtican-lauan lies below that of white oak only up to the 32d year and below that of the yellow poplar up to the 63d year. Above these points the curve rises rapidly until the trees attain diameters of 80 centimeters in the same period of time, one hundred thirty-nine years, as it takes yellow poplar to attain a diameter of 62 centimeters and white oak to attain a diameter of 46 centimeters.

From the above, it would seem that a forester working with rapidly growing species, such as *Parashorea plicata,* should obtain better results with regard to total volume production per year than could be obtained in temperate zones. It should be remembered, however, that dipterocarp forests contain a great mass of foliage that is not producing commercial wood, with the result that they are not as heavily stocked with dipterocarp species as are hardwood forests of temperate zones with species comparable to dipterocarps. As has been shown above, the forest of Mount Maquiling is not by any means a good dipterocarp forest, and the species, *Parashorea plicata* (bagtican-lauan), standing almost alone in the dominant tree class, is growing under much more favorable conditions than it would were it a component of the first story in a heavily stocked dipterocarp forest. The rates of growth which are shown by *Parashorea* under the above-mentioned conditions apparently are not duplicated by other species of the family Dipterocarpaceae growing in denser forests. A study of growth in other forests makes this apparent.

Measurements of growth were made in the forests of northern Laguna at an altitude of approximately 500 meters for the period from April 6, 1913, to April 6, 1914, for the following species: *Shorea squamata* (mayapis), *Shorea teysmanniana* (tiaong), *Shorea polysperma* (tanguile), *Hopea pierrei* (dalindingan-isak), and *Dipterocarpus* spp. (apitong and panao). The results of these measurements are given in Tables XVIII to XXII. From these tables the ages of trees of different diameters were calculated, and the results are plotted in fig. 2. In this figure also appear the same curves for white oak and yellow poplar as were plotted in connection with that for *Parashorea plicata* on Mount Maquiling. In all of these the growth below 5 centimeters was omitted. A comparison of figs. 1 and 2 shows

that the species of northern Laguna grow much more slowly than does *Parashorea plicata* on Mount Maquiling. Thus, it takes *Shorea teysmanniana*, the most rapidly growing of all the northern Laguna species, one hundred two years to grow from 5 centimeters to 50 centimeters in diameter, while *Parashorea* makes the same growth in eighty-three years. *Dipterocarpus*

TABLE XVIII.—*Annual diameter growth of Shorea squamata (mayapis). Northern Laguna forest, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	0 to 10.		10 to 20.		20 to 30.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	7.6	0.345	18.2	0.768	22.3	0.461
2	9.1	0.198	10.8	0.362	21.5	0.207
3	7.5	0.559	16.1	0.148	26.1	0.329
4	7.5	0.345	14.9	0.773	26.6	0.625
5	6.1	0.905	10.2	0.542	22.8	0.722
6	8.9	0.346	15.4	0.493	28.9	0.806
7	9.6	0.115	10.6	0.082	20.1	0.280
8	9.9	0.148	19.0	0.214	29.9	0.099
9	8.4	0.197	12.8	0.247	20.3	0.231
10	7.7	0.296	12.7	0.148	28.8	0.115
11	7.4	0.066	14.4	0.033	26.2	0.329
12	7.5	0.263	17.4	0.164	23.8	0.099
13			13.3	0.148	21.4	0.296
14			11.6	0.263		
15			13.0	0.411		
16			17.0	0.477		
17			15.4	0.230		
Total		3.783		4.768		4.599
Average		0.316		0.280		0.354
Years in class	31.6		35.7		28.2	

No. of tree in class.	Diameter class in centimeters.					
	30 to 40.		40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	34.7	0.263	40.5	0.625	57.0	0.263
2	31.7	0.575	48.0	0.181		
3	37.9	0.000	41.3	0.460		
4	39.2	0.346				
5	37.5	0.181				
6	35.4	0.016				
7	35.2	0.560				
8						
9						

TABLE XVIII.—*Annual diameter growth of Shorea squamata (mayapis). Northern Laguna forest, Laguna Province, Luzon*—Continued.

No. of tree in class.	Diameter class in centimeters.					
	30 to 40.		40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
10						
11						
12						
13						
14						
15						
16						
17						
Total		1.941		1.266		0.263
Average		0.277		0.422		0.263
Years in class	36.1		23.7		38.0	

TABLE XIX.—*Annual diameter growth of Shorea teysmanniana (tiaong). Northern Laguna forest, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.							
	0 to 10.		10 to 20.		20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	8.1	0.444	16.6	0.099	29.8	0.888	31.3	0.889
2	9.0	0.142	11.6	0.608	20.6	0.362	39.1	0.263
3	8.9	0.527	16.1	0.822	24.0	0.345	34.6	0.575
4	7.5	0.592	14.8	0.280	23.3	0.740	35.3	0.263
5	8.5	0.329	17.6	0.542	27.7	0.427		
6	7.4	0.082	19.6	0.427	29.4	0.872		
7	7.2	0.198	13.5	0.493	20.9	0.477		
8	8.6	0.230	11.4	0.016	20.2	0.428		
9	6.9	0.049	17.3	0.033				
10	7.2	0.609	13.4	0.329				
11	9.2	0.066	17.6	0.164				
12	9.8	0.115	10.6	0.362				
13	9.2	0.197	15.2	0.263				
14			11.7	0.905				
15			12.2	0.758				
16			11.2	0.000				
17			17.8	0.428				
Total		3.580		6.529		4.539		1.990
Average		0.275		0.384		0.567		0.497
Years in class	36.3		26.1		17.6		20.1	

TABLE XIX.—*Annual diameter growth of Shorea teysmanniana (tiaong). Northern Laguna forest, Laguna Province, Luzon*—Continued.

No. of trees in class.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	48.7	0.099	56.0	0.395	72.9	1.332
2	49.3	0.000	52.6	0.493	70.5	0.888
3	40.6	0.724	53.1	0.427		
4	46.3	0.772				
5	46.5	0.460				
6	43.6	0.855				
7	49.9	0.412				
8	44.6	1.032				
9						
10						
11						
12						
13						
14						
15						
16						
17						
Total		4.354		1.315		2.220
Average		0.544		0.429		1.110
Years in class	18.3		23.3		9.0	

TABLE XX.—*Annual growth of Shorea polysperma (tanguile). Northern Laguna forest, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.							
	0 to 10.		10 to 20.		20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	7.0	0.312	19.4	0.132	20.3	0.148	32.8	0.197
2	8.7	0.231	13.8	0.411	29.4	0.460	33.6	0.658
3					26.7	0.608	31.6	0.132
4					26.7	0.164	35.2	0.510
5					28.0	0.955		
6					24.5	0.313		
7					24.4	0.263		
8					24.2	0.263		
9					21.6	0.263		
10					24.4	0.526		
Total		0.543		0.543		3.963		1.497
Average		0.271		0.271		0.396		0.374
Years in class	36.9		36.9		25.3		26.7	

TABLE XX.—*Annual growth of Shorea polysperma (tanguile). Northern Laguna forest, Laguna Province, Luzon*—Continued.

No. of tree in class.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	46.8	0.805	53.6	0.263	66.9	0.296
2	43.7	0.362	52.2	0.395		
3	46.9	0.493	53.0	0.427		
4	45.6	0.542	53.8	0.263		
5						
6						
7						
8						
9						
10						
Total		2.202		1.348		0.296
Average		0.550		0.337		0.296
Years in class	18.2		29.7		33.8	

TABLE XXI.—*Annual diameter growth of Hopea pierrei (dalindingan-isak). Northern Laguna forest, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.							
	0 to 10.		10 to 20.		20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	9.0	0.263	13.7	0.115	20.1	0.411	31.6	0.214
2	6.8	0.197	10.8	0.197	21.6	0.626		
3	7.7	0.197	10.9	0.247	24.0	0.231		
4	8.4	0.329	12.1	0.362	29.8	0.295		
5	8.1	0.313	11.4	0.099	20.5	0.428		
6	9.9	0.313	17.8	0.197	26.7	0.164		
7	9.9	0.099	10.7	0.214				
8	7.1	0.362	18.0	0.181				
9	8.4	0.230	11.7	0.164				
10	8.1	0.214	10.4	0.066				
11	9.8	0.247	12.9	0.164				
12	7.9	0.132	18.4	0.560				
13			10.8	0.263				
14			17.6	0.444				
15			18.7	0.164				
16			12.0	0.362				
17			13.0	0.345				
18			13.0	0.230				
19			12.6	0.132				
20			17.2	0.280				
21			11.5	0.345				
22			13.6	0.296				
23			13.0	0.313				
Total		2.896		5.740		2.155		0.214
Average		0.241		0.250		0.359		0.214
Years in class	41.5		40.0		27.8		46.7	

TABLE XXII.—*Annual diameter growth of Dipterocarpus spp. (panao and apitong). Northern Laguna forest, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.							
	0 to 10.		10 to 20.		40 to 50.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	7.0	0.033	12.5	0.148	46.8	0.000	67.0	0.189
2	6.9	0.148	15.2	0.132	42.0	0.230		
3			12.2	0.181	47.1	0.247		
4			12.3	0.066	47.3	0.362		
Total		0.181		0.527		0.839		0.189
Average		0.091		0.132		0.210		0.189
Years in class	109.9		75.7		47.6		52.9	

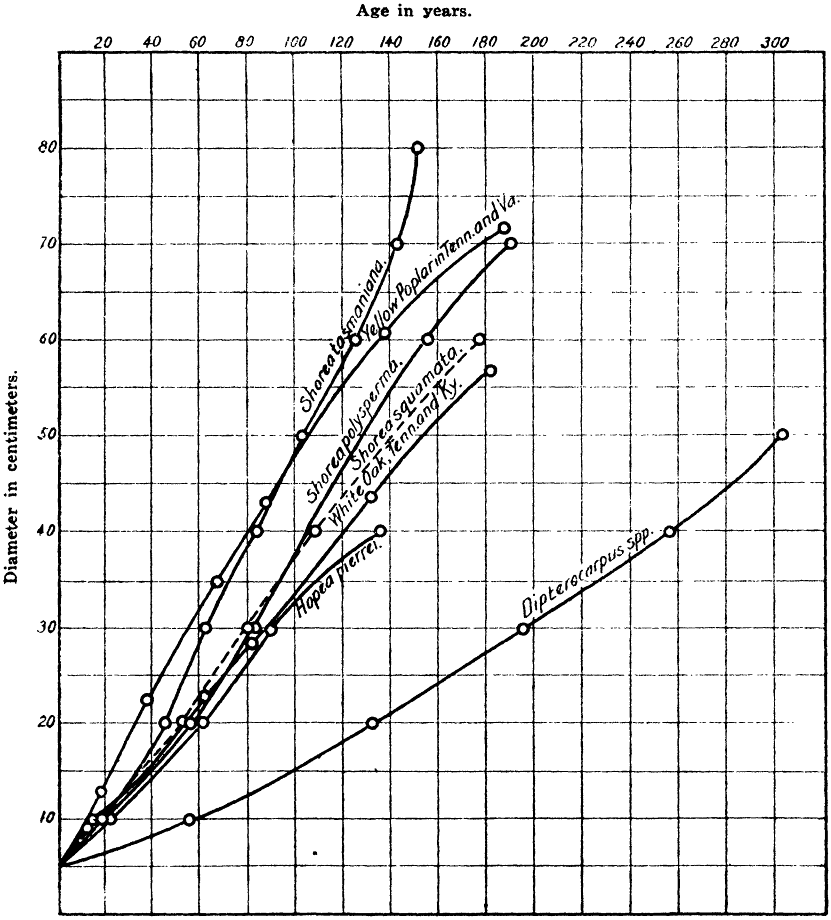


FIG. 2. Rates of growth of dipterocarps in northern Laguna Province, Luzon.

spp., the slowest of the group, takes three hundred three years to increase from 5 centimeters to 50 centimeters in diameter. It will be seen from the curve that individuals of *Shorea teysmanniana* between 60 and 80 centimeters make a very rapid growth. This part of the curve, however, is based on only 2 specimens, and the average of a large number of individuals would probably not show this rapid rate of growth. Certain large individuals of other species of dipterocarps growing in exceptionally favorable situations show similar rapid rates of growth, but this cannot be taken as an index of the rates of growth of the average large-sized trees.

A glance at the curves for dipterocarps of northern Laguna reveals the facts that only one species, *Shorea teysmanniana* (tiaong), lies above the curve for yellow poplar for any considerable distance; that *Shorea polysperma* (tanguile) is the only other species which shows itself much more successful in growth than white oak; that *Shorea squamata* (mayapis) is similar to oak in its development; and that *Hopea pierrei* and *Dipterocarpus* spp. lie below the temperate zone curves, *Dipterocarpus* spp. especially making a very poor showing in comparison with the temperate species. It is probable that *Parashorea plicata* (bagtican-lauan) may be a more rapid-growing species than any of the dipterocarps here considered, but it is also reasonable to suppose that the slower growth shown by these species is due to the more crowded conditions existing in the better stand in which they have developed. This supposition seems to be more reasonable when we pass to a consideration of the growth of dipterocarps in a still better-stocked stand of dipterocarps in Bataan Province.

It seems best to consider now the figures from Bataan Province which were collected on type area B at elevations of from 400 to 500 meters. Type area B represents a dense forest dominated by *Shorea polysperma*. The stand on this area is denser than that of either of the two areas previously discussed, and the site is probably better than that of either. The average yearly growth for dipterocarps on this area is given in Table XXIII. The ages of trees of different diameters, calculated from this table, appear in the form of curves of diameter on age in fig. 3. Individual curves are given for *Shorea polysperma*, *Dipterocarpus grandiflorus*, and *Pentacme contorta*, and a separate curve is presented compiled from the averages of all the individuals of dipterocarps measured on the area. In compiling these curves the trees were considered as originating at 5 centimeters. The actual ages, of course, are much greater than

those indicated by the curves, but for the practical management of existing forests this treatment has been justified (see page 476).

Shorea polysperma, which in northern Laguna is considerably slower growing than *Shorea teysmanniana* in the same area, is the fastest-growing species measured on type area B, Bataan. However, it shows a slower rate of growth on type area B than in northern Laguna. Thus, in one hundred twenty-seven years it grows from 5 to 50 centimeters in northern Laguna, while it

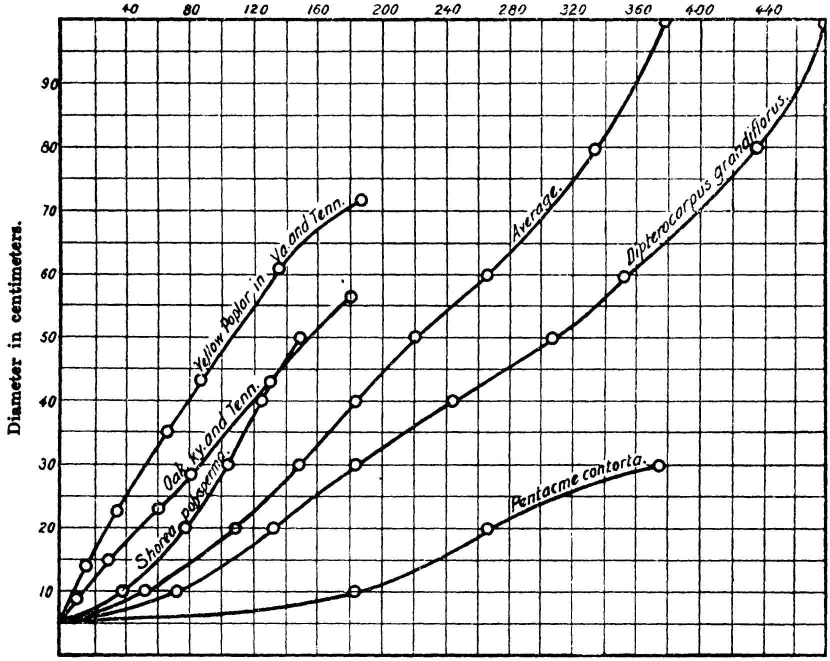


FIG. 3. Rates of growth of dipterocarps. Type area B, Bataan Province, Luzon.

requires one hundred fifty years to make the same growth on type area B. Referring to fig. 6, in which are presented the average curves of growth for the dipterocarps of each area, it will be seen that the curve for type area B lies below that of northern Laguna. This would seem to strengthen our conclusion that dipterocarps as a class grow slower as the density of stand increases. It does not follow from this that the volume of timber produced per year in the denser stands will be less than that in open stands, as the greater number of individuals in the denser stands may more than make up for the slower rate of growth of the individual trees.

TABLE XXIII.—*Annual diameter growth of dipterocarps. Type area B. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.							
	0 to 5.		5 to 10.		10 to 20.		20 to 30.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Shorea polysperma (tanguile)	3.5	0.016			16.8	0.573	25.2	0.128
Do	3.8	0.004			15.6	0.000	23.2	0.174
Do	4.5	0.115	8.9	0.091	10.1	0.075	26.4	0.340
Do			8.9	0.178	11.1	0.265	23.2	0.538
Do			8.3	0.099	13.1	0.000	21.0	0.182
Do			7.3	0.140	11.4	0.178	28.6	0.810
Do					10.8	0.456		
Do					13.7	0.515		
Total		0.135		0.508		2.062		2.172
Average		0.045		0.127		0.257		0.362
Years in class	111.1		39.5		38.8		27.6	
Dipterocarpus grandiflorus (apitong)	3.8	0.000	7.9	0.024	14.0	0.324	28.0	0.158
Do			7.9	0.004	19.1	0.039	21.0	0.111
Do			8.9	0.008	14.6	0.202	22.9	0.004
Do			9.6	0.000	11.1	0.198	21.7	0.508
Do			8.6	0.145	13.7	0.168		
Do			9.7	0.127	12.1	0.085		
Do			5.1	0.134	13.0	0.077		
Do			6.4	0.138	12.7	0.224		
Do			6.4	0.000				
Do			7.9	0.044				
Do			5.4	0.129				
Total		0.000		0.753		1.317		0.781
Average				0.068		0.165		0.195
Years in class			73.5		60.6		51.2	
Pentacme contorta (white lauan)			7.0	0.000	17.8	0.222	24.8	0.039
Do			5.7	0.010	18.8	0.328	22.9	0.166
Do			5.4	0.036	14.0	0.008	21.0	0.075
Do			5.4	0.063	13.6	0.138		
Do					11.4	0.000		
Do					10.2	0.039		
Shorea guiso (guijo)	4.5	0.079	7.0	0.210				
Do			8.5	0.128				
Anisoptera thurifera (palosapis)			9.2	0.122	18.1	0.099		
Total, all dipterocarps		.214		1.711		4.233		3.233
Average, all dipterocarps		.043		0.085		0.183		0.249
Years in class, all dipterocarps	116		56.1		54.6		40.1	

TABLE XXIII.—*Annual diameter growth of dipterocarps. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	30 to 40.		40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Shorea polysperma (tanguile)	33.4	0.622	40.8	0.317		
Do	34.1	0.376	45.7	0.297		
Do	38.8	0.455	40.4	0.630		
Do	31.2	0.645	45.8	0.392		
Do						
Do						
Do						
Do						
Total		2.098		1.636		
Average		0.520		0.409		
Years in class	19.3		24.5			
Dipterocarpus grandiflorus (apitong)	38.5	0.146	44.5	0.297	57.0	0.079
Do	35.0	0.131	42.9	0.059	52.8	0.447
Do	31.2	0.000	41.0	0.071	56.0	0.111
Do	38.5	0.039	43.9	0.186	54.3	0.372
Do	36.5	0.202	40.1	0.277	54.8	0.107
Do	31.8	0.448	40.1	0.087		
Do						
Do						
Do						
Do						
Do						
Total		0.966		0.977		1.116
Average		0.161		0.163		0.223
Years in class	62.1		61.3		44.8	
Pentacme contorta (white lauan)						
Do						
Do						
Do						
Do						
Do						
Shorea guiso (guijo)						
Do						
Anisoptera thurifera (palosapis)						
Total, all dipterocarps		3.064		2.613		1.116
Average, all dipterocarps		0.306		0.261		0.223
Years in class, all dipterocarps	32.6		38.1		44.8	

TABLE XXIII.—*Annual diameter growth of dipterocarps. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	60 to 80.		80 to 100.		110 to 120.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Shorea polysperma (tanguile)			96.00	0.277		
Do						
Do						
Do						
Do						
Do						
Do						
Do						
Total				0.277		
Average				0.277		
Years in class			72.2			
Dipterocarpus grandiflorus (apitong)	63.4	0.170	86.2	0.498	110.0	0.103
Do	62.0	0.226	88.5	0.209		
Do	74.9	0.368	83.0	0.376		
Do	76.0	0.333	93.4	1.040		
Do	73.0	0.139				
Do						
Do						
Do						
Do						
Do						
Do						
Total		1.236		2.123		0.103
Average		0.247		0.531		0.103
Years in class	81.0		37.6		97	
Pentacme contorta (white lauan)						
Do						
Do						
Do						
Do						
Do						
Shorea guiso (guijo)						
Do						
Anisoptera thurifera (palosapis)	76.2	0.535				
Total, all dipterocarps		1.771		2.400		0.103
Average, all dipterocarps		0.296		0.48		0.103
Years in class, all dipterocarps	67.6		41.6		97.0	

A study of the curves for type area B shows that not one of the species dominant in this forest is as successful in its growth as are the temperate species. Data for the rate of growth of *Shorea polysperma* (tanguile) are lacking for the larger size classes, and as the curve of growth for this species crosses that of white oak at the age of 132 years when it has reached the diameter of 43 centimeters it is possible that this species might in later years prove more successful; but, from the data at hand, no such conclusion can be drawn. It will be noted from the curves that the average rate of growth of all dipterocarps is only about half that of yellow poplar. Thus,

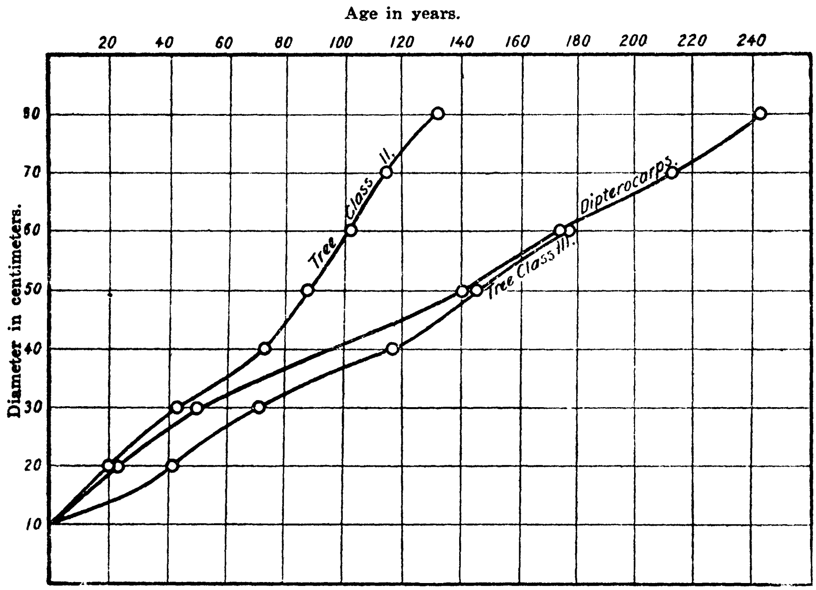


FIG. 4. Rates of growth of trees. Type area A, Bataan Province, Luzon.

yellow poplar grows from 5 to 60 centimeters in one hundred thirty-three years, while the average dipterocarp requires two hundred sixty-seven years to make the same growth. *Dipterocarpus grandiflorus* and *Pentacme contorta,* which are very prominent in this region, grow at a very much slower rate. Owing to the presence in this dipterocarp forest of a dense mass of foliage which is not producing commercial timber, it is not to be expected that the density of the dipterocarp forest will counterbalance the slow rate of growth in producing a volume of timber per year equal to that produced by good forests in the temperate zones. It is possible that under management a pure dipterocarp forest of the most successful species of the

region might be developed, but the obstacles in the way of such an achievement, at present, seem practically insurmountable. It is probable that for the next few hundred years, at least, foresters working in the Philippines will have to be content in the main with the present composition of dipterocarp forests.

The next area to be considered is that of type area A which is located just below type area B, Bataan, at elevations of from

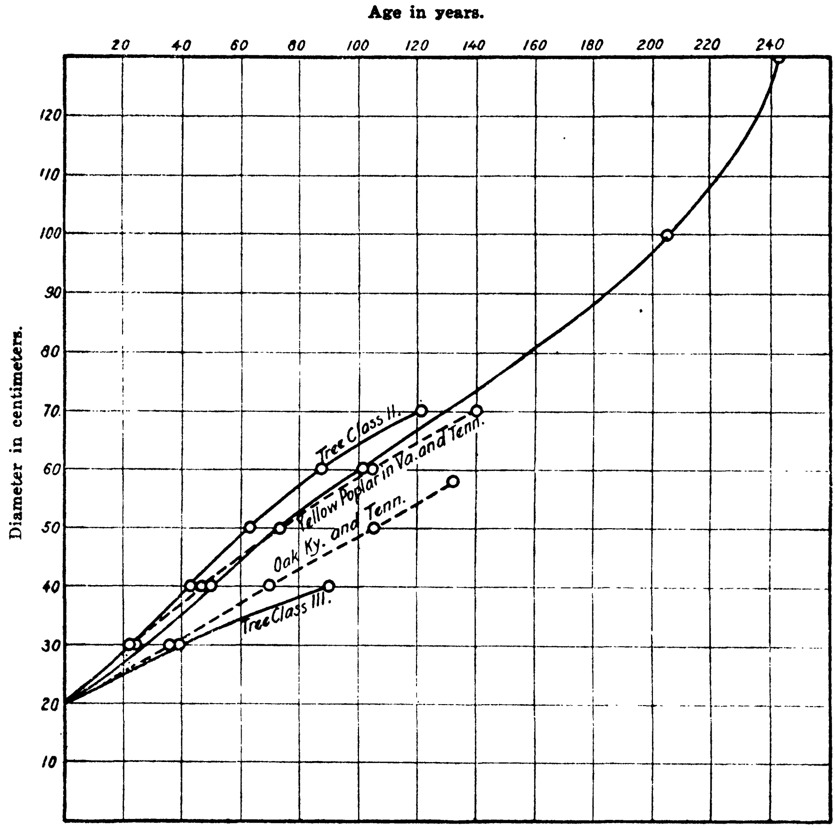


FIG. 5. Rates of growth of trail trees.

approximately 100 to 200 meters. Here the forest has been cut over to a considerable extent, but the openings have been largely closed by a growth of vines, shrubs, and small trees. The rates of growth for this area are given in Table XXIV. The curves of growth compiled from the averages given in Table XXIV appear in fig. 4. The average rate of growth of dipterocarps in this area is only slightly greater than that of dipterocarps on type area B. Thus, the average time required for the dip-

terocarps to grow from 10 to 80 centimeters on type area A is two hundred forty-two years and on type area B two hundred eighty-one years. The growth of dipterocarps of diameters larger than 20 centimeters on the two areas shows even greater similarity as will be seen by referring to fig. 6, in which are plotted the average rates of growth of all dipterocarps above 20 centimeters for each of the areas considered.

A number of trees were measured at elevations of from approximately 50 to 100 meters on a trail leading up to type area A. Here the forest has been very badly cut over and has been very largely replaced by a growth of *Schizostachyum mucronatum* (boho). The only dipterocarps measured were large ones, which for the most part overtopped the boho. The average yearly rate of growth for the dipterocarps is given in Table XXV, and the curve of growth appears in fig. 5. It will be seen from the curve that the trees along the trail, all of which are more than 20 centimeters in diameter, show a rate of growth greater than those on either type area A or B and approximately equal to those in northern Laguna. This increased rate of growth is shown in all size classes from 20 centimeters up, and is probably due in part to the more favorable situation at lower elevations and in part to the opening up of the forest.

In fig. 6 the rates of growth of dipterocarps more than 20 centimeters in diameter, on all of the areas under discussion, are compared with each other and with the rates of growth of yellow poplar and white oak. An examination of this figure shows that the larger individuals of the dipterocarps on type areas A and B in Bataan grow about as fast as white oak; that those in northern Laguna and the trail trees in Bataan make a more rapid growth, which is about equal to that of yellow poplar; and that *Parashorea plicata* is the fastest growing of all the species under discussion.

The last area to be considered is that of type area C, lying above type area B, at an elevation of 700 meters. Table XXVI contains figures on the rates of growth of dipterocarps at this elevation. This area is near the upper limit of the dipterocarp forest, and as is to be expected the average rate of growth of dipterocarps as shown therein is very much slower than that at the lower elevations.

We have thus far been considering only the rates of growth of our main crop, the dipterocarps, and have left out of consideration the rates of growth of trees of the second and third classes. The understories must, however, be taken into consideration. In heavy dipterocarp forests their bulk is incon-

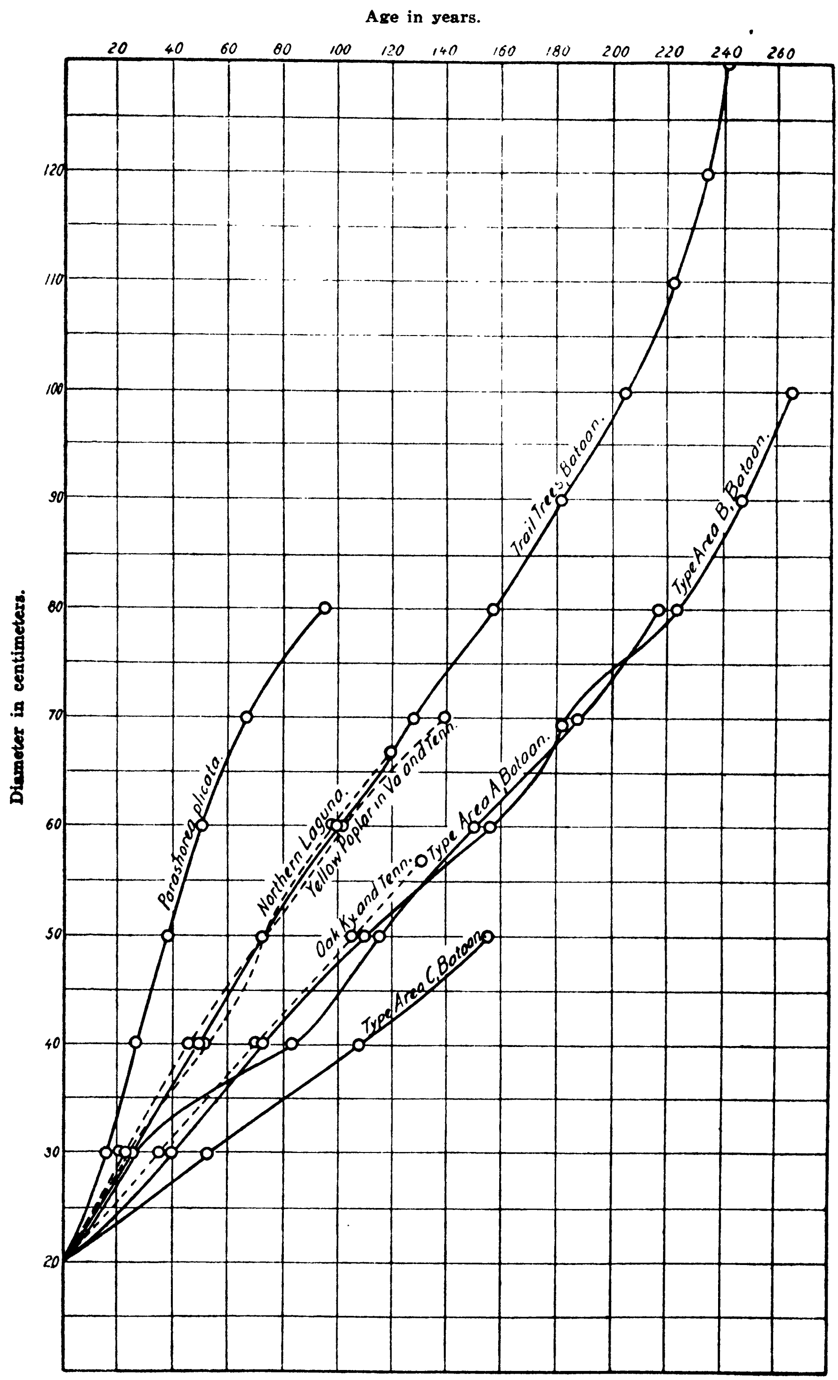


FIG. 6. Comparison of rates of growth of dipterocarps.

TABLE XXIV.—*Annual diameter growth of dipterocarps. Tree Class I. Type area A. Bataan Province, Luzon.*

[Figures are given in centimeters.]

Species.	Diameter class in centimeters.							
	10 to 20.		20 to 30.		30 to 40.		40 to 50.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Shorea guiso (guijo)	18.8	0.745	23.2	0.170	31.5	0.044		
Do	17.8	0.312	25.2	0.237	39.1	0.230		
Do	20.0	0.605						
Pentacme contorta (white lauan)	12.1	0.103						
Do	16.6	0.008						
Dipterocarpus verni ciflu-us (panao)	13.1	0.624	26.7	0.541			45.3	0.476
Do			25.8	0.584			44.5	0.327
Do							41.0	0.508
Anisoptera thurifera (palosapis)	18.8	0.525			32.5	0.170		
Shorea polysperma (tanguile)								
Total		2.922		1.532		0.444		1.311
Average		0.417		0.383		0.148		0.437
Years in class	23.9		26.1		67.6		22.8	

Species.	Diameter class in centimeters.					
	50 to 60.		60 to 70.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Shorea guiso (guijo)	50.4	0.198				
Do						
Do						
Pentacme contorta (white lauan)	51.8	0.443				
Do					73.6	0.170
Dipterocarpus vernicifluus (panao)	55.4		65.5	0.240		
Do	51.2	0.301	62.0	0.285		
Do						
Anisoptera thurifera (palosapis)	51.5	0.539				
Shorea polysperma (tanguile)					72.0	0.508
Total		1.481		0.525		0.678
Average		0.296		0.262		0.339
Years in class	33.8		38.1		29.5	

siderable when compared with the bulk of the main stand, but they are always present in large numbers, although owing to their greater diversity and smaller size they are of little commercial importance when compared with the dipterocarps. However, they occupy growing space both in the soil and in the

TABLE XXV.—*Annual diameter growth of dipterocarps. Trees of Class I. Trail trees in Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.							
	20 to 30.		30 to 40.		40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Anisoptera thurifera (palosapis)			33.7	0.237	47.7	0.882	54.1	0.297
Do					41.6	0.222	57.9	0.204
Dipterocarpus vernicifluus (panao)			35.3	0.375	49.0	0.171	50.9	0.357
Do								
Do								
Shorea guiso (guijo)	24.5	0.575						
Total		0.575		0.612		1.275		0.858
Average		0.575		0.306		0.425		0.286
Years in class	17.4		32.6		23.5		34.9	
	60 to 70.		70 to 80.		90 to 100.		100 to 110.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Anisoptera thurifera (palosapis)	63.7	0.614	73.8	1.118	94.0	0.455	106.0	0.059
Do								
Dipterocarpus vernicifluus (panao)	61.2	0.267	72.0	0.059				
Do	60.0	0.202						
Do	67.0	0.495						
Shorea guiso (guijo)					99.9	0.178		
Total		1.578		1.177		0.633		0.059
Average		0.394		0.588		0.316		0.059
Years in class	25.3		17.0		31.9		169.5	
	110 to 120.		120 to 130.		130 to 140.		160 to 170.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Anisoptera thurifera (palosapis)	114.0	0.049			132	0.000	167.0	.277
Do			129.2	2.335				
Dipterocarpus vernicifluus (panao)			127.9	1.230				
Do								
Do								
Shorea guiso (guijo)			125.8	0.233				
Total		0.049		3.798		0.000		0.277
Average		0.049		1.266		0.000		0.277
Years in class	204.1		7.9				36.1	

canopy, and thereby lessen the total amount of commercial wood produced. It is to be expected that during their early stages they will show rates of growth approximately equal to those of the dipterocarps, but as they increase in diameter without becoming dominant their rates of growth will become slower than those of the dipterocarps, and the growth of class III will be even slower than that of class II. Measurements of rates of growth of these classes were taken in all of the areas in Bataan; also, in the Maquiling forest. The results are given in Tables XXVII to XXXVIII, and growth curves for each area are plotted in figs. 4, 5, 7, and 8, along with the average growth curve for dipterocarps in the same areas.

The largest number of measurements were taken on type area B, Bataan, which, as mentioned above, represents a good dip-

TABLE XXVI.—*Annual diameter growth of trees of Class I. Dipterocarps. Type area C. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	10 to 20.		20 to 30.		30 to 40	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Hopea acuminata (dalindingan)	17.2	0.073	28.6	0.240	36.8	0.094
Do	15.9	0.000	26.1	0.153	36.8	0.276
Do			21.0	0.094	39.4	0.164
Shorea polysperma (tanguile)						
Pentacme contorta (white lauan)					30.5	0.035
Dipterocarpus vernicifluus (panao)			22.3	0.265		
Anisoptera thurifera (palosapis)					31.2	0.329
Total		0.073		0.752		0.898
Average		0.036		0.188		0.179
Years in class	274		53.2		55.9	

Species.	Diameter class in centimeters.					
	60 to 70.		70 to 80.		100 to 110.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Hopea acuminata (dalindingan)						
Do						
Do						
Shorea polysperma (tanguile)			76.8	0.134	107.0	1.23
Pentacme contorta (white lauan)	63.5	0.412				
Dipterocarpus vernicifluus (panao)						
Anisoptera thurifera (palosapis)						
Total		0.412		0.134		1.23
Average		0.412		0.134		1.23
Years in class	24.3		74.6		81.3	

terocarp forest. In fig. 7 for this area we find the curves of growth for classes II and III occupying the position which we would expect them to do in any virgin forest. During the early stages the growth of all classes is approximately equal. The curve for class III is the lowest, that for class II is the next, and the one for dipterocarps lies above both the others and rises rapidly after the dipterocarps have reached the dominant story.

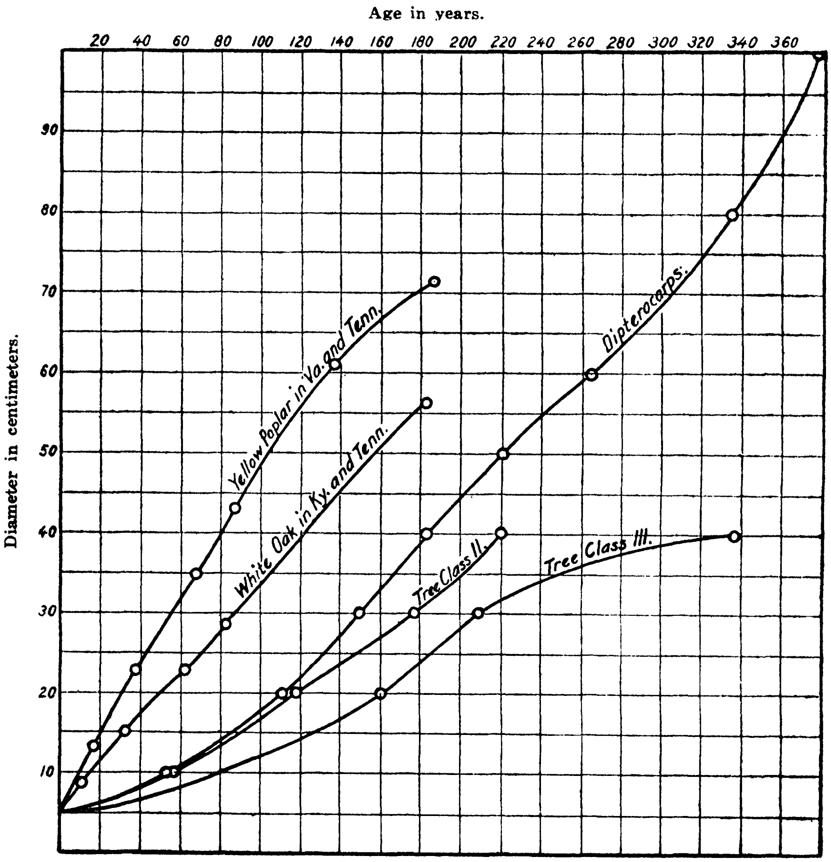


FIG. 7. Rates of growth of trees. Type area B, Bataan Province, Luzon.

In fig. 4 for type area A, Bataan, where owing to cutting the trees of class II are more prominent than in the virgin forest, we find this class developing at a more rapid rate than the dipterocarps, while tree class III is but slightly inferior to the dipterocarps in rate of growth. In fig. 5 for the trail trees, where there has been excessive cutting, we again find class II making a more rapid rate of growth than do the dipterocarps, while class III is still below both of the other classes.

Referring to fig. 8 for the Maquiling forest, we have represented curves of growth for *Celtis philippensis* (malaicmo),

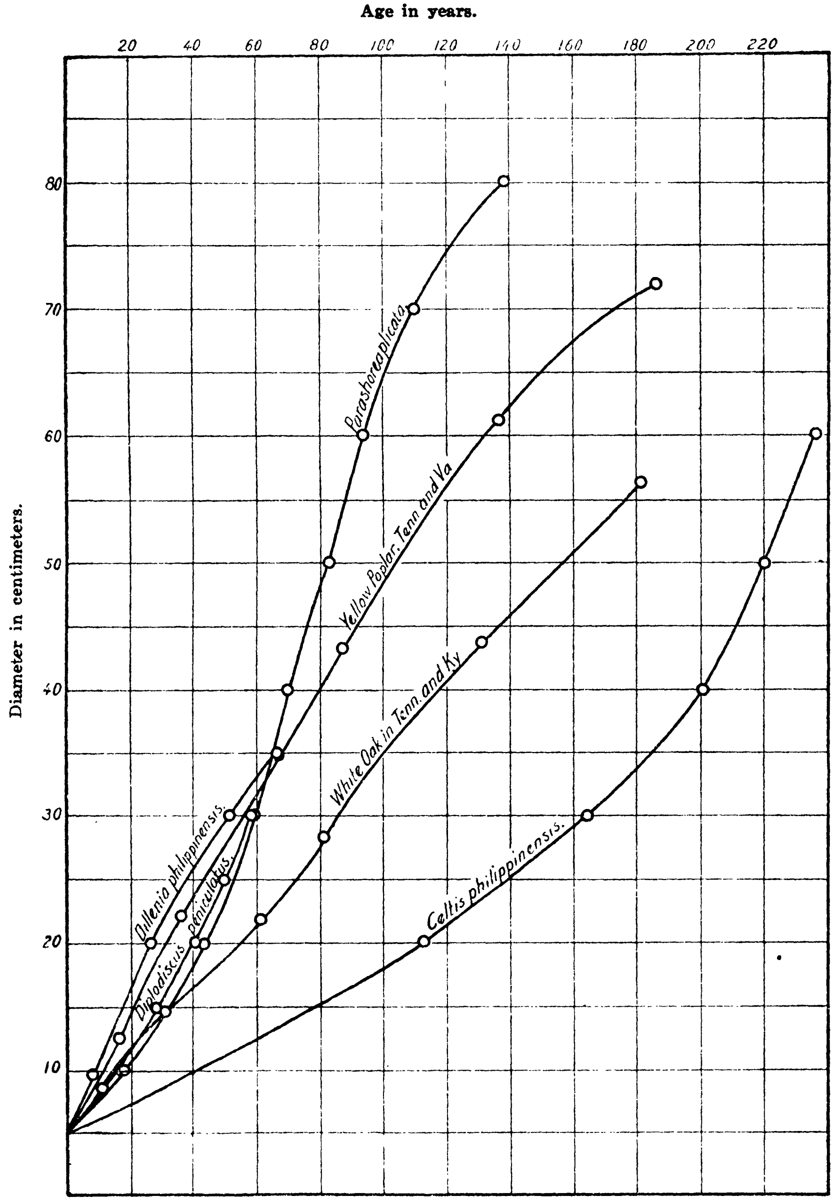


FIG. 8. Rates of growth of trees in forest of Mount Maquiling, Laguna Province, Luzon.

Dillenia philippinensis (catmon), and *Diplodiscus paniculatus* (balobo). Malaicmo is a typical second-class tree which, due to

the heavy cutting that has been carried on in the Maquiling forest, has attained a more or less dominant position. Its rate of growth is noticeably slow. *Diplodiscus* and *Dillenia* are typical third-class trees and never achieve dominance. Their rates of growth are also slow, but curiously more rapid than that of *Celtis* and, in the case of *Dillenia,* much more rapid than that of *Parashorea* in its younger stages. However, *Dillenia* is a short-boled tree that never attains great height and which develops a large crown. It is natural, therefore, that the same amount of growth distributed over a short bole should result in a more rapid diameter increment than when distributed over a longer bole as in the case of the dipterocarps. It may be that the results shown by these curves are due to peculiarities of the individual species and are probably not as correct as those for type area B, which are made from a larger number of trees growing in a virgin forest.

TABLE XXVII.—*Annual diameter growth of trees of Class II. Type area B. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Calophyllum blancoi (palomaria del monte)	4.1	0.257	7.3	0.248	15.3	0.266
Do	4.2	0.103	5.7	0.055	18.1	0.277
Do	3.8	0.111	5.7	0.138	13.7	0.407
Do			6.4	0.079	12.4	0.138
Do			8.6	0.154	15.3	0.297
Do			5.4	0.034	10.5	0.131
Do			9.5	0.046	18.1	0.067
Do			8.3	0.130		
Santiria nitida (alupag macsin)			6.0	0.048	15.3	0.016
Do			8.6	0.000	19.4	0.071
Do					14.6	0.067
Myristica philippensis (duguan)			9.5	0.146		
Sideroxylon duclitan (duclitan)					17.2	0.166
Sideroxylon sp					15.3	0.206
Eugenia sp					18.4	0.146
Eugenia glaucicalyx (mareeg)						
Do						
Eugenia sp. (malaruhat)			6.4	0.028	10.2	0.099
Ormosia calavensis (bahay)						
Mangifera altissima (pahutan)					17.5	0.000
Total		0.471		1.106		2.354
Average		0.157		0.092		0.157
Years in class	31.8		54.3		63.7	

TABLE XXVII.—*Annual diameter growth of trees of Class II. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.			
	20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.
Calophyllum blancoi (palomaria del monte)	20.9	0.027		
Do	25.2	0.139		
Do	20.7	0.360		
Do	20.1	0.158		
Do				
Do				
Do				
Do				
Santiria nitida (alupag macsin)	22.6	0.229	37.6	0.059
Do			38.8	0.067
Do				
Myristica philippensis (duguan)				
Sideroxylon duclitan (duclitan)				
Sideroxylon sp				
Eugenia sp	21.0	0.095		
Eugenia glaucicalyx (mareeg)			32.7	0.253
Do			31.2	0.039
Eugenia sp. (malaruhat)				
Ormosia calavensis (bahay)			37.8	0.772
Mangifera altissima (pahutan)				
Total		1.008		1.190
Average		0.168		0.238
Years in class	59.5		42.0	

TABLE XXVIII.—*Annual diameter growth of trees of Class III. Type area B. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Aporosa sp. (bignay)	4.8	0.118	6.1	0.055	10.4	0.032
Do	4.8	0.166	5.1	0.099	11.1	0.028
Do			5.1	0.103	11.4	0.075
Do			6.1	0.186	10.1	0.052
Do			8.6	0.020	14.9	0.229
Do			7.6	0.028	13.4	0.099
Do			6.7	0.078		
Do			8.3	0.000		
Do			6.4	0.126		
Do			5.1	0.040		
Do			7.6	0.075		

TABLE XXVIII.—*Annual diameter growth of trees of Class III. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Aporosa sp. (bignay)			5.4	0.130		
Do			7.3	0.059		
Do			9.8	0.059		
Do			7.6	0.087		
Do			5.4	0.020		
Do			6.7	0.028		
Do			6.1	0.115		
Do			5.4	0.040		
Do			5.4	0.104		
Cinnamomum mercadoi (similing)	3.5	0.059	6.1	0.079	13.0	0.036
Do	4.5	0.158	6.1	0.004	12.8	0.138
Do			9.2	0.126	10.1	0.138
Do			6.4	0.099	10.8	0.099
Talauma villariana (patanguis)			6.7	0.020	18.8	0.119
Litsea sp	3.8	0.113			15.3	0.071
Ellipanthus luzonensis						
Antidesma bunius (bignay)			5.4	0.020		
Gonocaryum calleryanum (malasamat)						
Canthium sp						
Do						
Ternstroemia toquian (bicag)			8.9	0.024	15.6	0.040
Do			6.7	0.047	13.0	0.015
Do			8.6	0.115	12.4	0.000
Do					13.1	0.059
Do					17.2	0.059
Do					16.5	0.087
Pygeum preslii			5.4	0.412		
Kopsia longiflora			9.5	0.016		
Euphorbiaceae			6.4	0.202	13.0	0.063
Do			7.6	0.091	19.7	0.048
Do			9.9	0.313	16.2	0.305
Do					17.8	0.014
Daphniphyllum sp	3.8	0.071	9.6	0.071		
Do	4.8	0.039				
Symplocos oblongifolia			5.4	0.436	11.1	0.151
Do			7.6	0.000		
Do			5.7	0.265		
Do			5.4	0.123		
Do			7.6	0.269		
Undetermined			7.0	0.000		
Do			8.3	0.032		
Do			5.4	0.065		
Cyclostemon bordenii (talimorong)					10.1	0.079
Cyclostemon microphyllus (talimorong)			5.4	0.079	16.2	0.234
Memecylon ovatum (culis)			7.9	0.048	10.5	0.081
Do			6.7	0.109	11.1	0.059
Do			6.1	0.028		
Litchi philippinensis			9.5	0.008		

TABLE XXVIII.—*Annual diameter growth of trees of Class III. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	0 to 5.		5 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Litchi philippinensis			7.9	0.000		
Diospyros sp. (bolongeta)			5.4	0.069		
Randia sp. (malabacauan)			5.7	0.122		
Do			6.7	0.175		
Cariuas					18.4	0.158
Knema heterophylla (tambalao)						
Malasamat			9.8	0.039		
Champereia manillana					13.7	0.210
Citrus hystrix (cabuyao)					12.1	0.020
Total		0.724		5.078		2.798
Average		0.103		0.096		0.093
Years in class	48.5		52.1		107.5	

Species.	Diameter class in centimeters.			
	20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.
Aporosa sp. (bignay)	21.9	0.780		
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Do				
Cinnamomum mercadoi (similing)			32.7	0.079
Do				
Do				
Do				
Talauma villariana (patanguis)				
Litsea sp	22.2	0.010		

TABLE XXVIII.—*Annual diameter growth of trees of Class III. Type area B. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.			
	20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.
Ellipanthus luzonensis	29.6	0.000		
Antidesma bunius (bignay)				
Gonocaryum calleryanum (malasamat)	21.3	0.049		
Canthium sp	22.2	0.297		
Do	28.0	0.039		
Ternstroemia toquian (bicag)				
Do				
Do				
Do				
Do				
Do				
Pygeum preslii				
Kopsia longiflora				
Euphorbiaceae	21.7	0.206		
Do	28.9	0.146		
Do				
Do				
Daphniphyllum sp				
Do				
Symplocos oblongifolia	23.5	0.475		
Do				
Do				
Do	22.9	0.135		
Do				
Undetermined	21.0	0.237		
Do				
Do				
Cyclostemon bordenii (talimorong)				
Cyclostemon microphyllus (talimorong)				
Memecylon ovatum (culis)				
Do				
Do				
Litchi philippinensis				
Do				
Diospyros sp. (bolongeta)				
Randia sp. (malabacauan)				
Do				
Cariuas				
Knema heterophylla (tambalao)	22.6	0.105		
Malasamat				
Champereia manillana				
Citrus hystrix (cabuyao)				
Total		2.479		0.079
Average		0.206		0.079
Years in class	48.5		126.5	

TABLE XXIX.—*Annual diameter growth of miscellaneous species. Trees of Class II. Type area A. Altitude 100 to 200 meters. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	10 to 20.		20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Calophyllum blancoi (palomaria del monte)			24.2	0.312	39.7	0.273
Do			27.1	0.565		
Mangifera altissima (pahutan)	12.8	0.158				
Palaquium sp. (bocboc)						
Eugenia sp. (malaruhat na puti)					38.5	0.476
Do						
Dracontomelum cumingianum (lamio)	18.2	1.168				
Myristica philippensis (duguan)	18.2	0.608				
Palaquium philippense (tagatoy)					34.7	0.619
Albizzia acle (acle)	19.8	0.985	22.3	0.252		
Koordersiodendron pinnatum (amuguis)	15.2	0.285				
Do	16.8	0.277				
Palaquium tenuipetiolatum (manicnic)	18.4	0.377				
Do	19.7	0.119				
Illipe ramiflora (baniti)			26.1	0.598		
Ficus variegata (tangisang bayawak)					38.8	0.202
Artocarpus sp. (sulipa)					33.1	0.131
Parinarium corymbosum (liusin)						
Canarium villosum (pagsahingin)						
Quercus sp. (cateban)						
Canangium odoratum (ylang-ylang)						
Pterocymbium tinctorium (taluto)						
Total		3.977		1.727		1.701
Average		0.496		0.432		0.340
Years in class	20.2		23.1		29.4	

Species.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Calophyllum blancoi (palomaria del monte)	44.8	0.871				
Do						
Mangifera altissima (pahutan)	45.5	1.024				
Palaquium sp. (bocboc)			53.3	1.168		
Eugenia sp. (malaruhat na puti)	41.0	0.515				
Do	43.5	0.532				
Dracontomelum cumingianum (lamio)						
Myristica philippensis (duguan)						
Palaquium philippense (tagatoy)						
Albizzia acle (acle)						

TABLE XXIX.—*Annual diameter growth of miscellaneous species. Trees of Class II. Type area A. Altitude 100 to 200 meters. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Koordersiodendron pinnatum (amuguis)						
Do						
Palaquium tenuipetiolatum (manicnic)						
Do						
Illipe ramiflora (bauiti)						
Ficus variegata (tangisang bayawak)			56.5	0.989		
Artocarpus sp. (sulipa)						
Parinarium corymbosum (liusin)						
Canarium villosum (pagsahingin)	47.7	0.327				
Quercus sp. (cateban)			53.8	0.337		
Canangium odoratum (ylang-ylang)					69.7	0.783
Pterocymbium tinctorium (taluto)			58.9	0.206		
Total		3.269		2.700		0.783
Average		0.654		0.675		0.783
Years in class	15.3		14.8		12.8	

Species.	Diameter class in centimeters.					
	70 to 80.		80 to 90.		90 to 100.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Calophyllum blancoi (palomaria del monte)						
Do						
Mangifera altissima (pahutan)	76.0	0.741			92.3	0.158
Palaquium sp. (bocboc)						
Eugenia sp. (malaruhat na puti)						
Do						
Dracontomelum cumingianum (lamio)						
Myristica philippensis (duguan)						
Palaquium philippense (tagatoy)						
Albizzia acle (acle)						
Koordersiodendron pinnatum (amuguis)	76.3	0.682				
Do	71.9	0.565				
Palaquium tenuipetiolatum (manicnic)						
Do						
Illipe ramiflora (baniti)						
Ficus variegata (tangisang bayawak)						
Artocarpus sp. (sulipa)						
Parinarium corymbosum (liusin)	72.0	0.269				
Canarium villosum (pagsahingin)						
Quercus sp. (cateban)						
Canangium odoratum (ylang-ylang)						
Pterocymbium tinctorium (taluto)						
Total		2.257				0.158
Average		0.564				0.158
Years in class	17.7				63.3	

TABLE XXX.—*Annual diameter growth of miscellaneous species. Trees of Class III. Type area A. Altitude from 100 to 200 meters. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	0 to 10.		10 to 20.		20 to 30.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Strombosia philippinensis (tamayuan)			16.6	0.548	22.0	0.119
Do			19.4	0.467	22.3	0.103
Do			19.4	0.735	29.6	0.099
Do			17.2	0.451	28.3	0.308
Aglaia macrobotrys (malatumbaga)					27.7	0.753
Cyathocalyx globosus (latuan)						
Ficus nota (tibig)					20.4	0.785
Santiria nitida (alupag macsín)			18.2	0.194		
Chisochiton philippinus (catang macsín)					20.0	0.305
Carra						
Baccaurea tetrandra (dilac)			15.6	0.000		
Cyclostemon bordenii (diladila)			18.8	0.119		
Do			11.8	0.111		
Do			12.5	0.075		
Do			14.9	0.134		
Antidesma edule (malatumbaga pula)			10.8	0.000		
Radermachera pinnata (banay-banay)			15.3	0.075		
Talauma villariana (patanguis)			17.8	0.000		
Urandra luzoniensis (mabunut)			12.4	0.305	22.9	0.455
Diospyros pilosanthera (bolongeta)	8.0	0.079	10.5	0.510		
Do			10.2	0.257		
Do			13.4	0.109		
Garcinia sp. (malabago)			13.4	0.328		
Celtis philippensis (malaicmo)			15.8	0.158		
Turpinia pomifera (malabago)			16.6	0.316	26.1	0.075
Do			14.9	0.269		
Nephelium sp. (malatumbaga)						
Polyscias nodosa (tocod langit or malapapaya).					22.6	0.308
Planchonia spectabilis (lamog)			10.5	0.079		
Reinwardtiodendron merrillii (malacamanga).			15.0	0.431		
Antidesma sp. (malauay)			12.7	0.495		
Santiria nitida (alupag macsín)						
Chisochiton tetrapetalus (catang macsín)						
Semecarpus perrottetii (ligas)			12.1	0.079		
Ficus ampelos (malaisis)						
Buchanania florida (balinghasay)						
Garcinia binucao (bilucao)						
Talauma villariana (patanguis)						
Mitrephora merrillii (lanutan)			11.1	0.012		
Undetermined						
Euphorbiaceae (calucoy)						
Total		0.079		6.257		3.310
Average		0.079		0.240		0.331
Years in class	126.6		41.6		30.2	

TABLE XXX.—*Annual diameter growth of miscellaneous species. Trees of Class III. Type area A. Altitude from 100 to 200 meters. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	30 to 40.		40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Strombosia philippinensis (tamayuan)						
Do						
Do						
Do						
Aglaia macrobotrys (malatumbaga)						
Cyathocalyx globosus (latuan)	36.3	0.150	44.0	0.548		
Ficus sp. (tibig)						
Santiria nitida (alupag macsín)	39.2	0.491				
Chisochiton philippinus (catang macsín)						
Carra			49.5	0.305		
Baccaurea tetrandra (dilac)						
Cyclostemon bordenii (diladila)						
Do						
Do						
Do						
Antidesma edule (malatumbaga pula)						
Radermachera pinnata (banay-banay)						
Talauma villariana (patanguis)						
Urandra luzoniensis (mabunut)	32.5	0.000				
Diospyros pilosanthera (bolongeta)	39.5	0.111				
Do						
Do						
Garcinia sp. (malabago)						
Celtis philippensis (malaicmo)						
Turpinia pomifera (malabago)						
Do						
Nephelium sp. (malatumbaga)	38.6	0.604				
Polyscias nodosa (tocod langit or malapapaya).						
Planchonia spectabilis (lamog)						
Reinwardtiodendron merrillii (malacamanga).						
Antidesma sp. (malauay)						
Santiria nitida (alupag macsín)			43.2	0.443		
Chisochiton tetrapetalus (catang macsín)	33.4	0.000				
Semecarpus perrottetii (ligas)						
Ficus ampelos (malaisis)			46.2	0.184		
Buchanania florida (balinghasay)					50.3	0.337
Garcinia binucao (bilucao)			48.2	0.285		
Talauma villariana (patanguis)	31.8	0.126				
Mitrephora merrillii (lanutan)						
Undetermined	33.4	0.287				
Euphorbiaceae (calucoy)					58.9	0.285
Total		1.769		1.765		0.622
Average		0.221		0.353		0.311
Years in class	45.3		28.3		32.1	

TABLE XXXI.—*Annual diameter growth of trees of Class II. Miscellaneous species. Trail trees. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.					
	20 to 30.		30 to 40.		40 to 50.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Ficus variegata (tangisang bayauac)			38.1	1.484		
Eugenia sp. (malaruhat puti)						
Planchonia spectabilis (lamog)						
Myristica sp. (tambalao)	24.8	0.412				
Do	26.7	0.426				
Celtis philippensis (malaicmo)	20.7	0.415			49.7	0.341
Do					46.2	1.405
Euphoria cinerea (alupag)	26.7	0.093	32.1	0.535		
Cyathocalyx globosus (latuan)	29.6	0.812	33.7	0.178	43.6	0.158
Palaquium tenuipetiolatum (manicnic)						
Canarium villosum (pagsahingin)	22.6	0.358	35.3	0.467	49.6	0.672
Do			34.3	0.692		
Lagerstroemia speciosa (banaba)			37.2	0.164	46.4	0.443
Artocarpus communis (antipolo)			32.4	0.198		
Do						
Nauclea sp. (calamansanay)					46.8	0.059
Radermachera pinnata (banay-banay)			33.1	0.198	40.7	0.562
Do			39.7	0.118	41.1	0.020
Bombax ceiba (malabulac)						
Do						
Terminalia nitens (calumpit)						
Do						
Albizzia procera (acleng parang)			33.1	0.862		
Albizzia saponaria (salinkugi)	23.8	0.693				
Sarcocephalus cordatus (bancal)						
Zizyphus zonulatus (balacat)			35.0	0.771		
Undetermined (lago?)						
Total		3.209		5.667		3.660
Average		0.478		0.515		0.457
Years in class	21.8		19.4		21.9	

Species.	Diameter class in centimeters.					
	50 to 60.		60 to 70.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Ficus variegata (tangisang bayauac)						
Eugenia sp. (malaruhat puti)			64.0	0.084		
Planchonia spectabilis (lamog)	52.1	0.193	61.0	0.561		
Myristica sp. (tambalao)						
Do						
Celtis philippensis (malaicmo)						
Do						
Euphoria cinerea (alupag)						
Cyathocalyx globosus (latuan)						
Palaquium tenuipetiolatum (manicnic)	56.2	0.582				
Canarium villosum (pagsahingin)						
Do						
Lagerstroemia speciosa (banaba)	57.9	0.257				

TABLE XXXI.—*Annual diameter growth of trees of Class II. Miscellaneous species. Trail trees. Bataan Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	50 to 60.		60 to 70.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Artocarpus communis (antipolo)			68.5	0.000		
Do			60.8	0.592		
Nauclea sp. (calamansanay)						
Radermachera pinnata (banay-banay)						
Do						
Bombax ceiba (malabulac)	58.8	0.297				
Do	50.6	0.364				
Terminalia nitens (calumpit)	51.9	0.950			79.5	0.095
Do	51.5	0.297				
Albizzia procera (acleng parang)						
Albizzia saponaria (salinkugi)						
Sarcocephalus cordatus (bancal)			63.2	0.008		
Zizyphus zonualtus (balacat)						
Undetermined (lago?)			63.6	0.535		
Total		2.940		1.780		0.095
Average		0.420		0.296		0.095
Years in class	23.8		33.8		105.3	

TABLE XXXII.—*Annual diameter growth of trees of Class III. Miscellaneous species. Trail trees. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.							
	10 to 20.		20 to 30.		30 to 40.		40 to 50.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Chisochiton tetrapetalus (catang-macsin)			21.3	0.188				
Chisochiton philippinus (catang-macsin)			26.4	0.134				
Phaeanthus ebracteolatus (bantian)			22.2	0.416				
Aphananthe philippinensis (alasiis)			23.8	0.079				
Carallia integerrima	18.2	0.614						
Pithecolobium scutiferum (anagap)			29.6	0.219				
Mallotus philippensis (banato)			29.2	0.106				
Streblus sp			26.7	0.247	33.1	0.302		
Undetermined			22.6	0.689	33.1	0.099		
Calucoy							42.6	1.040
Clausena anisum-olens (caytana)			22.6	0.200				
Total		0.614		2.278		0.401		1.040
Average		0.614		0.253		0.200		1.040
Years in class	16.2		39.5		50.0		9.6	

TABLE XXXIII.—*Annual diameter growth of trees of Class II. Miscellaneous species. Type area C. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.							
	0 to 10.		10 to 20.		20 to 30.		30 to 40.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Eugenia cumingii			11.4	0.189				
Do			15.3	0.100				
Do			13.4	0.151				
Eugenia whitfordii (malaruhat)			12.7	0.000				
Do			10.2	0.006				
Eugenia glaucicalyx (mareeg)	8.9	0.084	15.2	0.200	23.5	0.153	33.7	0.182
Do	6.4	0.086	19.1	0.124				
Eugenia sp			16.6	0.045				
Do			11.4	0.092				
Do			12.1	0.268				
Do			17.2	0.272				
Do			10.8	0.132				
Quercus sp. (cateban)			13.4	0.127				
Do			14.0	0.282				
Cyclostemon sp					22.8	0.071		
Do					22.3	0.512		
Cyclostemon microphyllus (talimorong)			15.3	0.131				
Pygeum preslii (uto-uto)					21.7	0.335		
Calophyllum cumingii (palomaria)			19.7	0.259	23.5	0.176	30.5	0.100
Do							34.3	0.112
Myristica sp. (duguan)								
Plectronia umbellata (malabacauan)	6.4	0.094	10.2	0.188				
Do	5.7	0.125	10.2	0.059				
Undetermined							30.5	0.333
Gordonia fragrans			16.5	0.000				
Total		0.389		2.625		1.247		0.727
Average		0.097		0.138		0.249		0.182
Years in class	103.0		72.4		40.2		54.9	

Species.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Eugenia cumingii	47.7	0.129				
Do						
Do						
Eugenia whitfordii (malaruhat)						
Do						
Eugenia glaucicalyx (mareeg)			52.8	0.342		
Do						
Eugenia sp						
Do						
Do						

TABLE XXXIII.—*Annual diameter growth of trees of Class II. Miscellaneous species. Type area C. Bataán Province, Luzon*—Continued.

Species.	Diameter class in centimeters.					
	40 to 50.		50 to 60.		60 to 70.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Eugenia sp						
Do						
Quercus sp. (cateban)						
Do						
Cyclostemon sp						
Do						
Cyclostemon microphyllus (talimorong)						
Pygeum preslii (uto-uto)						
Calophyllum cumingii (palomaria)			50.8	0.405		
Do						
Myristica sp. (duguan)	46.4	0.047				
Plectronia umbellata (malabacauan)			53.3	0.341		
Do						
Undetermined					68.7	0.338
Gordonia fragrans			50.8	0.141		
Total		0.176		1.229		0.338
Average		0.088		0.307		0.338
Years in class	113.6		32.6		29.6	

TABLE XXXIV.—*Annual diameter growth of trees of Class III. Miscellaneous species. Type area C. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.			
	0 to 10.		10 to 20.	
	Diameter.	Growth.	Diameter.	Growth.
Memecylon ovatum (culis)	7.0	0.113	13.5	0.222
Do	8.9	0.084	17.2	0.118
Do	8.9	0.123	10.2	0.059
Do	5.1	0.099	11.4	0.188
Do	6.4	0.153	10.8	0.106
Do	7.6	0.066	15.3	0.267
Do			12.7	0.221
Do			11.4	0.129
Ternstroemia toquian (bicag)	9.5	0.066	13.4	0.194
Do			12.7	0.134
Aporosa microcalyx	5.7	0.082	13.4	0.005
Do	7.0	0.459		
Do	8.9	0.124		
Antidesma sp. (paitan)			10.4	0.163
Talauma villariana (patanguis)			15.2	0.000
Polyosma philippinensis (malapandacaqui)			13.5	0.118
Ardisia sp	5.7	0.000	19.7	0.010
Total		1.369		1.884
Average		0.124		0.126
Years in class	80.7		79.4	

TABLE XXXV.—*Annual diameter growth of Celtis philippinensis (malicmo) in forest of Mount Maquiling, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	5 to 10.		10 to 20.		20 to 30.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	5.3	0.144	15.2	0.128	29.6	0.192
2						
Average		0.144		0.128		0.192
Years in class	35		78		52	

No. of tree in class.	Diameter class in centimeters.			
	40 to 50.		50 to 60.	
	Diameter.	Growth.	Diameter.	Growth.
1	47.6	0.510	50.7	0.494
2			58.2	0.732
Average		0.510		0.613
Years in class	19		16	

TABLE XXXVI.—*Annual diameter growth of Diplodiscus paniculatus (balobo) in forest of Mount Maquiling, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	5 to 10.		10 to 15.		15 to 20.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	5.00	0.191	13.21	0.318	17.38	0.318
2	5.72	0.143	12.58	0.191	18.30	0.669
3	7.71	0.237	10.32	0.143	17.63	0.557
4	7.91	0.238	14.60	0.940	16.20	0.382
5	6.30	0.223	11.78	0.494	18.33	0.207
6	6.43	0.255	12.69	0.350	17.70	0.415
7	6.43	0.096	14.68	0.303		
8	7.41	0.636	14.55	0.574		
9	6.22	0.159	13.19	0.779		
10	7.62	0.477	13.20	0.382		
11	9.10	0.237	10.82	0.477		
12	7.10	0.620	12.10	0.478		
13	8.97	0.398	11.72	0.192		
14	9.80	0.159	12.00	0.508		
Total		4.069		6.129		2.548
Average		0.290		0.438		0.424
Years in class	17.2		11.4		11.8	

TABLE XXXVI.—*Annual diameter growth of Diplodiscus paniculatus (balobo) in forest of Mount Maquiling, Laguna Province, Luzon*—Continued.

No. of tree in class.	Diameter class in centimeters.			
	20 to 25.		25 to 30.	
	Diameter.	Growth.	Diameter.	Growth.
1	24.70	0.700	26.35	0.508
2	21.40	0.428	25.40	0.541
3	21.20	0.843		
4	23.10	0.415		
5	24.15	0.415		
6	21.80	0.572		
7				
8				
9				
10				
11				
12				
13				
14				
Total		3.373		1.049
Average		0.562		0.524
Years in class	8.9		9.5	

TABLE XXXVII.—*Annual diameter growth of Dillenia philippinensis (catmon) in forest of Mount Maquiling, Laguna Province, Luzon.*

[Diameter and growth are given in centimeters.]

No. of tree in class.	Diameter class in centimeters.					
	5 to 10.		15 to 20.		20 to 25.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
1	8.05	0.605	15.15	0.524	20.0	0.286
2					22.3	0.319
3					22.5	0.461
4					24.7	0.335
Total		0.605		0.524		1.401
Average		0.605		0.524		0.350
Years in class	8.3		9.5		14.2	

No. of tree in class.	Diameter class in centimeters.			
	25 to 30.		30 to 35.	
	Diameter.	Growth.	Diameter.	Growth.
1	27.9	0.477	33.9	0.319
2	28.1	0.366		
3	29.5	0.606		
4				
Total		1.449		0.319
Average		0.487		0.319
Years in scale	10.3		15.7	

TABLE XXXVIII.—*Annual diameter growth of trees of Class I. Miscellaneous species. Trail trees. Bataan Province, Luzon.*

[Diameter and growth are given in centimeters.]

Species.	Diameter class in centimeters.							
	20 to 30.		30 to 40.		50 to 60.		70 to 80.	
	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.	Diameter.	Growth.
Koordersiodendron pinnatum (amuguis)	26.7	0.480	32.1	2.510	53.1	0.257		
Dracontomelum dao (dao)	29.2	0.285	34.0	0.689	57.9	1.641	76.1	0.732
Total		0.765		3.199		1.898		0.732
Average		0.382		1.599		0.949		0.732
Years in class	26.1		6.3		10.5		13.6	

From the above data it is seen that as long as we maintain the dipterocarp canopy undisturbed the dipterocarps remain the fastest growing trees in the forest. By their existence in the dominant situations they hold down the miscellaneous species growing under them to such an extent that these species cannot enter into serious competition with them. However, a disturbance in the main canopy is accompanied, in every instance, by increased rates of growth of these species. They are generally more numerous than the smaller-sized dipterocarps, and when the opening in the canopy is large this fact enables such numbers of them to obtain dominant situations that they place many of the young dipterocarps at a great disadvantage.

Unregulated logging in dipterocarp forests will always result in a gradual change in composition and volume such as that described above. The need of great care in the regulation of any cutting in this forest is very apparent. Success over any large area cannot be expected from a mere rule of thumb, such as a diameter-limit regulation, for this will only accidentally so regulate the cutting in certain places that openings in the canopy will be made which dipterocarps are able to fill, and in a majority of cases will result in so favoring one or many of the minor species that dipterocarps will be placed at a great disadvantage or partially eliminated from the area.

We have yet to consider what can be expected of the dipterocarp forest at points near its upper limits. At elevations above 600 meters in most parts of the Islands the climate approaches that of the nonseasonal belt at lower elevations in everything except temperature. The rainfall is noticeably in-

creased due to increased cloudiness, the amount of light is less and the humidity is higher. Accompanying this is a reduction in temperature. It is to be expected that the reduction in the amount of light and the lower temperature will be reflected in a slower rate of growth, and such meager data as have been collected bear out this expectation. In Table XXVI are presented figures for the growth of all dipterocarps measured on type area C at an elevation of approximately 700 meters on Mount Mariveles, Bataan, and in Tables XXXIII and XXXIV similar figures for the miscellaneous trees of class II and class III are given. An examination of these tables shows very little difference in rates of growth between dipterocarps and the other tree classes, and the rates of growth shown therein are notably slow. When compared with the growth of yellow poplar, we find that it takes an average dipterocarp three hundred eighty-three years to grow from 10 centimeters in diameter to 40 centimeters, whereas it takes the yellow poplar but seventy years to make the same growth. The figures on which these results are based are too few to have great reliance placed upon them, but it is not probable that any error which may enter into the result will be sufficient entirely to vitiate them. It seems to be quite clear that above elevations of 600 meters little can be expected from forests in the Philippines in the production of commercial timber under any reasonable rotation. A striking fact which is suggested by the tables for species at this elevation is that even in a virgin forest there is probably little difference in the rates of growth of trees in the dominant class and those of classes II and III. The forest is, of course, more open than that at lower elevations, and the composition is less complex. This accounts in part for the ability of species of tree classes II and III to maintain rates of growth similar to that of trees of the main canopy, but it is also probable that conditions of growth have so changed from the optimum for dipterocarps that they have been reduced in their rates of growth to approximately the same as those of the second- and third-story trees which are more at home at this elevation.

We have already noted that the dipterocarps apparently show a more rapid rate of growth in open than in dense forests and that removing part of the main canopy, as in the case of type area A and the trail trees in Bataan, increases the rates of growth of tree classes II and III. These points are emphasized in the curves in which the rates of growth of the same tree class in different areas are compared. Comparing the rates of growth

of the dipterocarps in the various areas in Bataan (fig. 6), we find that those along the trail, where there has been very considerable cutting, grow faster than any of the others. Those in type area A, where there has been less cutting, and those in the virgin forest of type area B have about the same rate of growth. These curves do not show the rate of growth of trees less than 20 centimeters in diameter. If the smaller sizes were included, the dipterocarps on type area A would show faster rates of growth than those on type area B. Those on type area C, at a higher elevation, have a still slower rate of growth than those

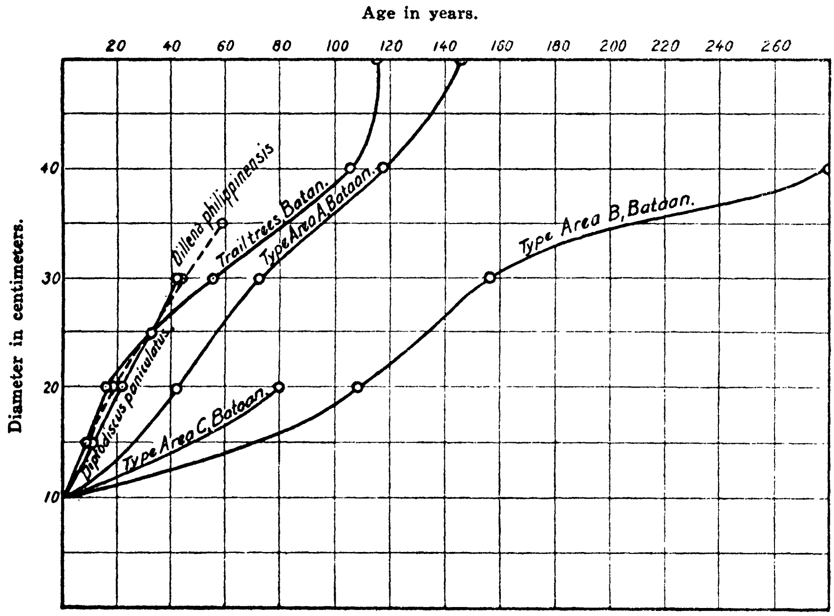


FIG. 9. Rates of growth of trees of class III.

on type area B. The last point on the curve for type area C was calculated, but it is probably not far from correct.

In fig. 9, in which the rates of growth of tree class III in the different areas are compared, it will be seen that the trail trees again make the fastest growth, those on type area A are next, while the growth of those on type area B is still slower. The curve for tree class III on type area C shows a more rapid rate of growth than that for type area B. This faster rate of growth in type area C is probably connected with the more open condition of the forest at the greater elevation.

In fig. 10, in which the rates of growth of tree class II are

compared, it will be seen that the trees on type area A and the trail trees have approximately equal rates of growth, which are faster than those of the trees on type areas B and C. Tree class III thus shows, as do the other classes, faster rates of growth in cut-over than in virgin forest. It is noticeable that the curves for tree classes II and III on the different areas

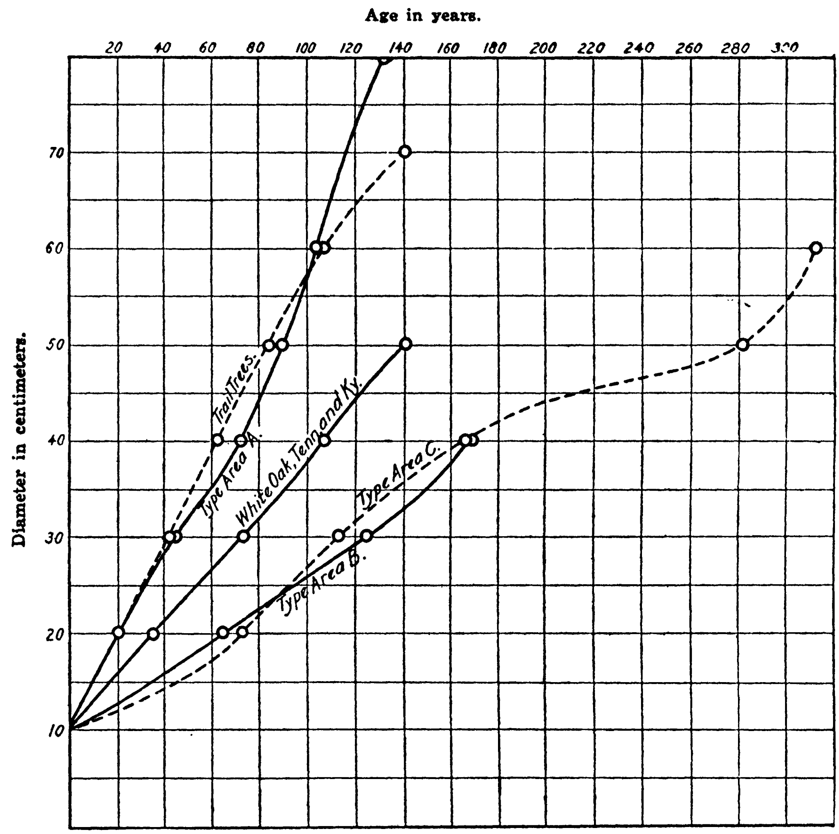


FIG. 10. Rates of growth of trees of class II. Bataan Province, Luzon.

show approximately the same relative positions as do those for the dipterocarps.

In fig. 11 are presented curves showing the age of individuals of different diameters of *Shorea robusta* growing in virgin stands. The data from which these curves were drawn were collected in India.[28]

[28] Caccia, A. M. P., A preliminary note on the development of the sal in volume and money value, *Indian Forest Rec.* (1908), 1, 85.

Along with the three curves of *Shorea robusta* in different situations, we have also presented a curve for *Parashorea plicata* on Mount Maquiling and one for *Shorea polysperma* on type area B, Bataan. The curve for *Parashorea plicata* shows a somewhat faster rate of growth than do any of those for

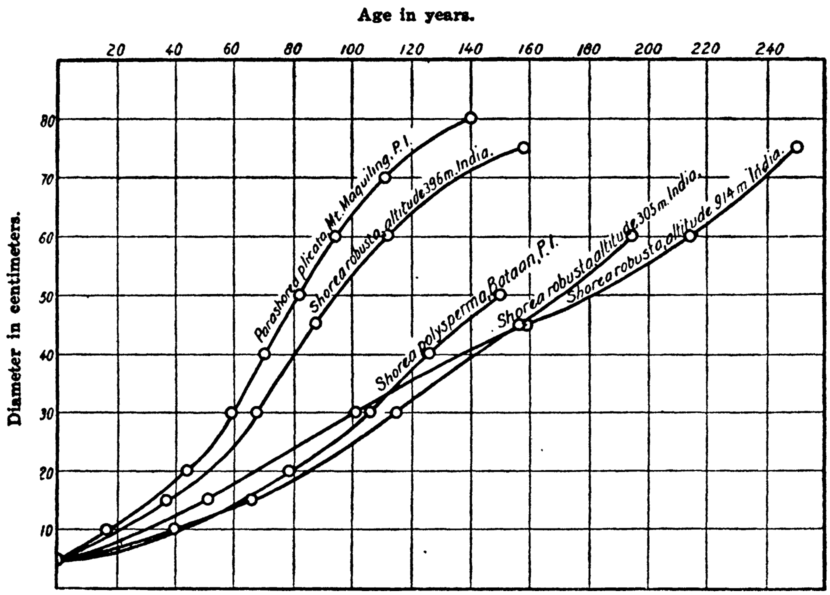


FIG. 11. **Rates of growth of *Shorea robusta* compared with those of Philippine dipterocarps.**

Shorea robusta, while the curve for *Shorea polysperma* shows a rate of growth not very different from the two curves for *Shorea robusta* drawn from data collected at elevations of 300 and 900 meters. It may be judged from this that the rates of growth of the dipterocarps in the Philippines are comparable with those of *Shorea robusta* in India.

(To be concluded.)

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PHILIPPINE DIPTEROCARP FORESTS

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(Concluded.)

SEASONAL DIAMETER GROWTH

Parashorea plicata was the only dipterocarp which it was practical to measure frequently enough to obtain seasonal records of growth, and for this reason such records are confined to it. Measurements of girth were made at intervals of approximately two months on the same trees that were used in obtaining yearly records. For the sake of comparison the girth records were reduced to terms of diameter growth for thirty-day periods. The results are recorded in Table XXXIX. The average rates of growth compiled from this table are plotted for all diameters in fig. 12. The most striking thing about the curves is that they show two periods of rapid and two of slow growth. The first period of slower growth is most apparent at the height of the dry season in April. After this, the rate of growth increases steadily until June and July, just after the beginning of the rainy season. From the end of July to the first of October there is another decided minimum, and following this from October to December there is another maximum. Beginning with December there is a slower growth, which reaches its minimum in April.

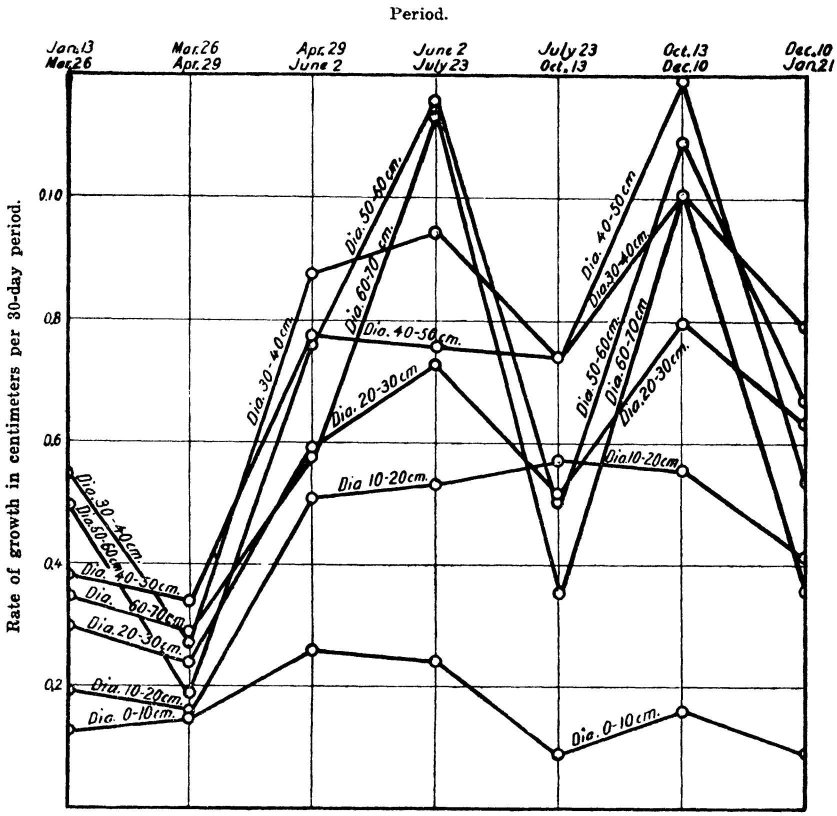

FIG. 12. Seasonal rates of growth of *Parashorea plicata*.

TABLE XXXIX.—*Seasonal diameter growth of Parashorea plicata. Mount Maquiling, Laguna Province, Luzon.*

[All numbers are reduced to rate in centimeters for thirty days.]

No. of tree.	Jan. 13 to Mar. 26.	Mar. 26 to Apr. 29.	Apr. 29 to June 2.	June 2 to July 23.	July 23 to Oct. 13.	Oct. 13 to Dec. 10.	Dec. 10 to Jan. 13.	Tree diameter.
18	0.013	0.028	0.000	0.028	0.006	0.008	0.000	5.19
19	0.020	0.056	0.000	0.019	0.000	0.000	0.000	3.88
20	0.000	0.000	0.000	0.000	0.000	0.000	0.000	2.26
30	0.000	0.014	0.070	0.019	0.017	0.025	0.023	4.15
32	0.000	0.000	0.000	0.000	0.000	0.000	0.023	7.40
85	0.053	0.028	0.042	0.056	0.017	0.041	0.000	7.29
86	0.025	0.000	0.056	0.056	0.029	0.058	0.023	9.11
90	0.000	0.014	0.042	0.019	0.006	0.000	0.000	6.28
Average	0.012	0.015	0.026	0.025	0.009	0.016	0.009	
42	0.013	0.014	0.000	0.009	0.012	0.049	0.000	14.92
50	0.079	0.070	0.084	0.103	0.105	0.107	0.079	19.35
55	0.007	0.028	0.028	0.019	0.022	0.041	0.011	15.00
60	0.026	0.028	0.084	0.094	0.064	0.107	0.045	19.55

TABLE XXXIX.—*Seasonal diameter growth of Parashorea plicata. Mount Maquiling, Laguna Province, Luzon*—Continued.

No. of tree.	Jan. 13 to Mar. 26.	Mar. 26 to Apr. 29.	Apr. 29 to June 2.	June 2 to July 23.	July 23 to Oct. 13.	Oct. 13 to Dec. 10.	Dec. 10 to Jan. 13.	Tree diameter.
63	0.000	0.000	0.028	0.037	0.076	0.016	0.000	13.21
64	0.000	0.000	0.042	0.019	0.035	0.025	0.011	17.38
65	0.013	0.000	0.028	0.028	0.052	0.058	0.040	15.78
66	0.013	0.000	0.028	0.037	0.022	0.008	0.023	12.72
69	0.019	0.000	0.000	0.000	0.022	0.041	0.011	18.90
70	0.000	0.000	0.042	0.047	0.058	0.049	0.023	17.20
77	0.013	0.000	0.126	0.112	0.105	0.066	0.011	16.20
81	0.013	0.000	0.042	0.047	0.047	0.049	0.000	12.10
83	0.026	0.056	0.042	0.047	0.052	0.049	0.000	11.09
84	0.000	0.000	0.042	0.065	0.058	0.082	0.000	19.42
87	0.046	0.000	0.112	0.103	0.099	0.074	0.079	12.61
88	0.073	0.028	0.096	0.094	0.047	0.074	0.068	10.15
153	0.000	0.014	0.056	0.028	0.041	0.008	0.000	14.00
157	0.000	0.028	0.042	0.084	0.087	0.074	0.341	14.80
158	0.013	0.042	0.042	0.047	0.076	0.074	0.023	14.19
Average	0.019	0.016	0.051	0.053	0.057	0.055	0.040	
14	0.053	0.056	0.028	0.028	0.029	0.066	0.000	25.70
22	0.039	0.013	0.112	0.093	0.093	0.148	0.114	27.50
23	0.013	0.028	0.028	0.075	0.070	0.091	0.034	29.20
37	0.000	0.028	0.028	0.065	0.058	0.066	0.000	29.95
41	0.086	0.070	0.084	0.122	0.099	0.091	0.034	27.00
43	0.020	0.014	0.096	0.075	0.064	0.074	0.000	22.65
45	0.006	0.000	0.042	0.084	0.047	0.049	0.000	26.50
47	0.053	0.028	0.084	0.037	0.047	0.173	0.045	25.55
56	0.019	0.028	0.042	0.056	0.047	0.058	0.034	20.80
61	0.007	0.042	0.014	0.037	0.035	0.025	0.023	26.95
72	0.013	0.028	0.014	0.065	0.029	0.041	0.011	26.15
73	0.093	0.056	0.140	0.168	0.105	0.156	0.068	29.00
79	0.000	0.000	0.084	0.084	0.041	0.115	0.227	28.90
80	0.046	0.014	0.112	0.093	0.058	0.082	0.454	26.85
154	0.000	0.014	0.014	0.037	0.012	0.016	0.011	26.00
162	0.086	0.028	0.126	0.112	0.070	0.115	0.091	27.90
163	0.026	0.000	0.084	0.065	0.035	0.066	0.034	26.50
166	0.000	0.000	0.000	0.028	0.012	0.025	0.023	27.95
167	0.000	0.000	0.000	0.056	0.022	0.049	0.000	22.20
Average	0.029	0.023	0.059	0.073	0.051	0.079	0.063	
12	0.079	0.084	0.070	0.103	0.093	0.099	0.068	39.60
21	0.026	0.028	0.042	0.196	0.116	0.132	0.011	36.20
25	0.000	0.014	0.014	0.065	0.058	0.099	0.000	30.40
31	0.053	0.070	0.154	0.037	0.022	0.091	0.034	38.65
35	0.000	0.000	0.042	0.037	0.035	0.066	0.000	33.00
51	0.079	0.042	0.112	0.218	0.105	0.115	0.091	39.00
74	0.000	0.000	0.056	0.009	0.052	0.033	0.011	36.55
78	0.099	0.014	0.084	0.084	0.118	0.132	0.091	34.60
155	0.026	0.014	0.042	0.084	0.047	0.049	0.011	31.65
159	0.053	0.028	0.210	0.196	0.116	0.247	0.023	35.40
160	0.053	0.028	0.112	0.103	0.093	0.082	0.079	33.50
161	0.186	0.000	0.112	0.000	0.029	0.066	0.011	39.75
Average	0.055	0.027	0.087	0.094	0.074	0.101	0.036	

TABLE XXXIX.—*Seasonal diameter growth of Parashorea plicata. Mount Maquiling, Laguna Province, Luzon*—Continued.

No. of tree.	Jan. 13 to Mar. 26.	Mar. 26 to Apr. 29.	Apr. 29 to June 2.	June 2 to July 23.	July 23 to Oct. 13.	Oct. 13 to Dec. 10.	Dec. 10 to Jan. 13.	Tree diameter.
11	0.073	0.028	0.042	0.075	0.070	0.099	0.056	45.70
15	0.039	0.000	0.028	0.075	0.116	0.115	0.136	46.80
16	0.039	0.056	0.042	0.103	0.058	0.099	0.056	42.75
17	0.020	0.014	0.084	0.131	0.122	0.173	0.079	44.10
24	0.046	0.000	0.084	0.047	0.093	0.148	0.068	49.25
26	0.013	0.042	0.084	0.065	0.076	0.099	0.011	48.60
28	0.007	0.070	0.070	0.075	0.076	0.107	0.045	45.50
29	0.039	0.070	0.112	0.112	0.118	0.148	0.093	47.50
34	0.046	0.014	0.102	0.075	0.064	0.099	0.000	43.10
38	0.006	0.042	0.042	0.047	0.087	0.008	0.000	44.25
46	0.000	0.000	0.028	0.056	0.070	0.132	0.023	43.40
48	0.013	0.042	0.056	0.056	0.058	0.091	0.023	40.90
49	0.026	0.000	0.028	0.019	0.064	0.082	0.045	43.25
52	0.046	0.014	0.084	0.084	0.099	0.214	0.000	46.80
53	0.060	0.028	0.126	0.075	0.099	0.238	0.023	46.75
54	0.007	0.084	0.084	0.047	0.029	0.107	0.079	47.35
57	0.079	0.126	0.168	0.150	0.087	0.107	0.079	40.75
58	0.099	0.140	0.266	0.141	0.163	0.238	0.148	42.50
59	0.026	0.000	0.084	0.130	0.064	0.082	0.000	43.30
62	0.020	0.000	0.028	0.037	0.058	0.099	0.023	49.20
67	0.000	0.000	0.028	0.037	0.029	0.041	0.011	46.70
82	0.073	0.028	0.056	0.019	0.022	0.082	0.000	46.75
89	0.007	0.056	0.084	0.093	0.105	0.148	0.182	48.80
152	0.053	0.070	0.056	0.084	0.052	0.082	0.034	49.75
156	0.113	0.000	0.112	0.084	0.052	0.181	0.068	41.10
164	0.079	0.000	0.084	0.112	0.070	0.124	0.045	49.00
165	0.026	0.000	0.056	0.037	0.012	0.049	0.000	43.40
171	0.000	0.000	0.056	0.047	0.052	0.141	0.125	46.00
Average	0.038	0.033	0.078	0.075	0.074	0.119	0.052	
33	0.013	0.042	0.056	0.019	0.070	0.000	0.000	54.60
44	0.053	0.028	0.056	0.093	0.093	0.115	0.034	54.90
168	0.053	0.000	0.084	0.112	0.076	0.124	0.056	59.50
169	0.000	0.000	0.042	0.093	0.000	0.173	0.045	54.50
170	0.000	0.000	0.014	0.141	0.000	0.033	0.000	51.15
172	0.093	0.000	0.084	0.206	0.035	0.173	0.125	51.15
173	0.086	0.042	0.196	0.150	0.082	0.148	0.205	58.15
Average	0.050	0.019	0.076	0.116	0.051	0.109	0.066	
27	0.080	0.000	0.000	0.000	0.000	0.049	0.034	67.10
40	0.020	0.000	0.000	0.028	0.070	0.058	0.079	62.80
68	0.066	0.056	0.210	0.225	0.017	0.247	0.227	64.50
71	0.026	0.000	0.070	0.374	0.017	0.082	0.056	62.70
75	0.033	0.084	0.070	0.075	0.076	0.099	0.000	60.25
76	0.013	0.028	0.000	0.019	0.070	0.082	0.136	60.50
151	0.000	0.028	0.060	0.075	0.000	0.082	0.023	63.20
Average	0.034	0.028	0.058	0.114	0.036	0.100	0.079	
39	0.013	0.028	0.014	0.000	0.058	0.066	0.011	78.90

These changes in growth coincide with climatic changes, and are very probably dependent upon them. The first period of slow growth occurs during the dry season. We have found that the percentage of soil moisture is not greatly decreased at this time, but the rate of evaporation is high. This high rate of evaporation not only checks the rate of growth, but very probably also causes a shrinkage in the trunk of the tree due to loss of water. Daily changes in the girth of trees growing in the open can be very readily detected by measurements taken at intervals throughout a period of twenty-four hours. Thus a change of nearly 0.5 millimeter has been noted in the diameter of a *Parashorea*, 1.14 meters in diameter, growing in the open on the grounds of the College of Agriculture at Los Baños. The change in girth takes the form of an increase during the latter part of the night and a decrease during the latter part of the day. This decrease is probably connected with the excessive evaporation rate occurring late in the afternoon. Since changes of as much as 0.5 millimeter can be detected in the course of twenty-four hours, it is not unreasonable to suppose that as great or greater changes may take place as the result of variation in the seasonal rate of evaporation.

In the same manner the increased rate of growth which we have noted in the early part of the rainy season may be due in part to a lower evaporation rate accompanied by a consequent swelling of the trunk. It is probable, however, that the increase is due more largely to the favorable conditions for growth obtaining at this time. The evaporation at this time is not so excessive as during the dry season, while at the same time the light conditions remain favorable. During the height of the rainy season the sky is overcast during a large portion of the time, and this probably accounts for the decreased rate of growth which is noted from July to October. In the period following this, moisture conditions continue to remain favorable and the amount of light increases. This increase in light intensity apparently accounts for the second period of rapid growth occurring from October to December. Beginning in December, when the dry season sets in, there is a slight but decided drop in temperature, and the rate of growth decreases. As stated before, this decrease culminates in April when the dry season is at its height. As might be expected, the tall trees, which are most exposed, show relatively greater changes in rates of growth than do the smaller ones under the main canopy where the environmental changes are not so great.

Consideration of the above facts, suggests that in tropical regions where a seasonal climate is pronounced, such rings of growth as are found in trees, if due at all to changes in climate, are more likely to be formed semiannually than annually. Also, it appears that to obtain accurate data as to yearly rate of growth of trees in the Philippines, measurements of standing trees must be made at the same time each year in order to avoid the inaccuracy which might result from seasonal changes in rates of growth or in the sizes of the trees.

GROWTH IN VOLUME

Data are at hand for computing the growth in volume for the main species of only one region, that of the northern Laguna forest. Growth in volume for the different species of this forest was computed by dividing the difference in volume between any two diameter classes by the number of years which it takes the species in question to grow from one of these classes to another. Growth in volume as far as we have been able to calculate it from the data at hand is given in Table XL.

From Table XL it is possible to compute the annual rate of growth in volume in cubic meters per hectare for the forest of northern Laguna by applying the figures on rate of volume growth to the figures given in Table VIII (see Laguna forest),

TABLE XL.—*Annual growth in volume of dipterocarps in northern Laguna forest.*

[Growth is given in cubic meters.]

Species.	Diameter in centimeters.				
	20.	25.	30.	35.	40.
Shorea teysmanniana (tiaong)	0.0140	0.0262	0.0300	0.0330	0.0382
Shorea squamata (mayapis)	0.0100	0.0150	0.0162	0.0205	0.0262
Hopea pierrei (dalindingan)	0.0100	0.0161	0.0135	0.0122	
Shorea polysperma (tanguile)	0.0093	0.0183	0.0192	0.0275	0.0350
Dipterocarpus sp. (apitong)	0.0041	0.0064	0.0084	0.0117	0.0172

Species.	Diameter in centimeters.				
	45.	50.	55.	60.	65.
Shorea teysmanniana (tiaong)	0.0471	0.0519	0.0609	0.0810	0.1170
Shorea squamata (mayapis)	0.0336	0.0381	0.0450		
Hopea pierrei (dalindingan)					
Shorea polysperma (tanguile)	0.0472	0.0476	0.0446	0.0465	0.0511
Dipterocarpus sp. (apitong)	0.0211				

TABLE XLI.—*Annual volume growth of 1 hectare of average forest in northern Laguna.*

[Growth is given in cubic meters.]

Species.	Diameter class in centimeters.				
	30.	35.	40.	50.	60.
Shorea squamata (maypis)	0.0865	0.0248	0.3361	0.3299	0.1565
Shorea teysmanniana (tiaong)	0.0948	0.0380	0.2796	0.3109	0.2414
Shorea polysperma (tanguile)	0.0157	0.0500	0.0399	0.1261	0.0381
Dipterocarpus sp. (apitong)	0.0125		0.0341	0.0190	
Dipterocarpus sp. (panao)	0.0027		0.0055	0.0047	
Pentacme contorta (white lauan)	0.0055		0.0313		0.0131
Hopea pierrei (dalindingan isak)	0.0427	0.0365	0.0993	0.0620	
Miscellaneous trees	0.1078	0.0807	0.2840	0.1504	0.0627
Total of all species	0.3682	0.2300	1.1098	1.0030	0.5118

Species.	Diameter class in centimeters.				Total.
	70.	80.	90.	100.	
Shorea squamata (mayapis)	0.0436	0.0349			1.0123
Shorea teysmanniana (tiaong)	0.1364	0.1364	0.0195	0.0195	1.2765
Shorea polysperma (tanguile)	0.0667	0.0540	0.0268	0.0811	0.4984
Dipterocarpus sp. (apitong)	0.0171				0.0827
Dipterocarpus sp. (panao)	0.0086				0.0215
Pentacme contorta (white lauan)		0.0086			0.0501
Hopea pierrei (dalindingan isak)					0.2405
Miscellaneous trees	0.0322				0.7178
Total of all species	0.3046	0.2339	0.0463	0.1006	3.9082

which represents the average number of trees per hectare in this forest. The results of these computations are presented in the form of volume growth for each diameter class of each species in Table XLI. The data presented in this table were obtained by multiplying the growth in volume for any species of any particular size by the number of trees of this species and diameter class as given in Table VIII. Where the growth data in Table XL do not extend to diameter classes which appear in the stand table, the growth in diameter for size classes not represented was assumed to be that of the highest diameter class measured for the species in question. One species, *Pentacme contorta* (white lauan), which appears in the stand table, is not represented in our volume growth table. The figures for volume growth of apitong were used in calculating the rate of growth of this species, in as much as the growth figures for apitong and white lauan have been found to be similar in another part of the Islands. Likewise, having no growth figures for

the miscellaneous species existing in the forest of northern Laguna, the figures for growth in diameter of tanguile, which were found to be about the average for the dipterocarps, were applied to the volume table for the miscellaneous species in calculating the growth of these species in the stand. These figures are probably erroneous for the higher diameter classes of the miscellaneous species, in as much as tanguile probably grows more rapidly than the large classes of these species. However, the majority of the miscellaneous species do not get into the larger diameter classes.

By reference to Table XLI we see that the greatest amount of growth is taking place in the diameter classes of 40 and 50 centimeters. This is due, in part, to the fact that trees of these sizes are growing at a rapid rate, but more largely to the fact that these trees constitute the bulk of the forest. The total amount of growth per hectare per year in this forest is 3.9 cubic meters. Since the bulk of the growth occurs in the lower diameter classes, if all the timber over 60 centimeters in diameter were removed from the forest, it would reduce the growth per hectare per year less than 0.7 cubic meter, and if the rate of growth of the smaller trees did not increase this forest would still be producing over 3.2 cubic meters per hectare per year. The reduction in rate of growth in volume per year would probably be insignificant, as the trees which were left on the ground would probably respond to the removal of the larger trees of the forest by increased rates of growth. Of the total annual production of 3.9 cubic meters per hectare, 0.7 cubic meter is produced by miscellaneous species other than dipterocarps. The balance, or 3.2 cubic meters, is produced by the dipterocarps alone.

The total growth of 3.9 cubic meters is the annual growth on a capital of 203.9 cubic meters, and is therefore a growth of 1.91 per cent. Assuming that the percentage of growth as shown by this forest is approximately normal for equal volumes of timber throughout the Philippine Islands, we are in a position to make an approximation of the total production of timber in the forests. Whitford estimates the total stand of timber of the Philippine Islands as 822,584,000 cubic meters. By applying our percentage growth of 1.91, we can estimate that the total annual production of timber in the Philippine Islands amounts to 15,711,000 cubic meters.

Statistics from the Bureau of Internal Revenue place the total amount of timber cut in the Philippine Islands per year at 277,171

cubic meters. It would appear from this that under any rational system of management we can increase our timber production about fifty-six times without in any way reducing our forest capital.

ENVIRONMENTAL CONDITIONS IN THE FOREST

The measurements of environmental factors here recorded were made on a ridge in the dipterocarp forest of Mount Maquiling, at an elevation of approximately 300 meters, and near the region in which growth measurements were taken. They cover nearly the same period as do the records of seasonal growth.

In discussing the distribution of dipterocarp forests in the Philippines, it was shown that the temperature at low elevations was remarkably uniform throughout the Archipelago and so its variations could hardly have any considerable influence in producing the differences between the types of vegetation which cover large areas in the lowlands. The temperature in the forest, however, will have to be taken into account in any explanation of the rates of growth shown by the trees.

Records of temperature in the forest of Mount Maquiling were taken about 75 centimeters above the ground by means of a Draper's recording thermometer. The results are presented in Table XLII in the form of maxima, minima, means, averages of daily maxima, and averages of daily minima for periods of four weeks. The means were taken from the original automatically traced records by means of a planimeter, and for this reason should be highly accurate. An inspection of Table XLII brings out two points: the temperature is remarkably uniform and it is not extraordinarily high. The mean temperature from January 3, 1913, to January 2, 1914, was 23°.1. The maximum for the year is 29°.7 and the minimum is 19°.4, the yearly range being 10°.3. The highest mean temperature for any of the four-week periods is 25°.1 and the lowest is 21°.7. The daily range is likewise small. The average maximum for the year is 25°.1 and the average minimum is 21°.6, making the average daily range 3°.5.

These figures show that the temperature under the forest cover is high enough at all times of the year to make growth possible. The temperatures, however, are never as high as those which are regarded as optimum for rapid growth, and for most of the time are probably about 10° below the optimum.

It is difficult to compare the effectiveness of temperature in

TABLE XLII.—*Temperature of undergrowth in forest of Mount Maquiling, Laguna Province, Luzon.*

[Degrees Centigrade.]

Period.	Maximum.	Minimum.	Mean.	Average daily maximum.	Average daily minimum.
Jan. 3 to Jan. 31	24.8	18.6	21.7	22.8	20.7
Jan. 31 to Feb. 28	25.6	18.9	21.9	23.7	20.5
Feb. 28 to Mar. 28	27.7	19.4	23.0	25.7	21.2
Mar. 28 to Apr. 25	28.0	19.4	23.8	26.4	21.7
Apr. 25 to May 23	28.3	20.5	24.1	26.6	22.4
May 23 to June 20	29.7	21.7	25.1	27.8	22.9
June 20 to July 18	27.7	20.5	23.8	25.8	22.2
July 18 to Aug. 15	27.4	21.1	23.3	25.2	22.3
Aug. 15 Sept. 12	27.4	20.5	23.4	25.3	21.9
Sept. 12 to Oct. 10	27.7	20.8	23.6	25.9	22.2
Oct. 10 to Nov. 7	25.8	19.4	22.7	24.6	21.7
Nov. 7 to Dec. 5	25.0	19.4	22.0	23.3	20.8
Dec. 5 to Jan. 2	25.0	19.7	21.7	22.7	20.8
Average	26.9	19.9	23.1	25.1	21.6

different regions in advancing growth. Livingston and Livingston [29] suggest a formula which should be useful, although, as they point out, the figures in it are tentative. They assume that the rate of growth is unity at 40° F. and that it doubles for each rise of 10° C. (18° F.) above this. The last assumption is based on recent experimental work on growth and other metabolic processes. If t is taken as the normal daily mean temperature on the Fahrenheit scale and if u is the corresponding temperature efficiency for growth, according to the assumption then—

$$u=2^{\frac{t-40}{18}}$$

The time element is taken into account by adding together the efficiency indices for all of the days of the frostless season. Following this method, Livingston and Livingston have prepared a chart of the temperature efficiencies in the United States.

Temperature on Mount Maquiling is so uniform that instead of calculating the efficiency for each day, we have made the calculation for the average of each four-week period, multiplied it by 28, and then added together the results for each period. The resulting efficiency is 1,360, which corresponds on the chart

[29] Livingston, B. S., and Livingston, G. J., Temperature coefficients in plant geography and climatology, *Bot. Gaz.* (1913), 56, 349.

of Livingston and Livingston to the southern end of Florida, the portion of the United States showing the highest temperature efficiency. The efficiency for Mount Maquiling is roughly twice that of Virginia, Kentucky, and Tennessee in the central hardwood region, from which were obtained the growth measurements of white oak and yellow poplar, which we have used for comparison with those of the dipterocarps.

This comparison of temperature efficiencies in the United States and in the forest of Mount Maquiling is, of course, by no means accurate. Livingston and Livingston do not assume that the equation on which these results are based is final; besides this, in any exact comparison we would have to take into consideration the daily range of temperature and the differences in the reactions of tropical and temperate zone plants.

TABLE XLIII.—*Temperature in forest of Mount Maquiling, Laguna Province, Luzon.*

[Degrees Centigrade.]

Period.	Undergrowth, average of weekly—		Second story, average of weekly—		Dominant tree, average of weekly—	
	Maxima.	Minima.	Maxima.	Minima.	Maxima.	Minima.
Jan. 3 to Jan. 31	23.8	20.0	25.1	19.5	30.9	19.1
Jan. 31 to Feb. 28	25.0	19.3	26.9	19.1	31.9	19.1
Feb. 28 to Mar. 28	26.8	20.0	27.9	19.4	37.2	20.2
Mar. 28 to Apr. 25	27.4	20.5	27.0	21.2	32.6	19.9
Apr. 25 to May 23	27.5	21.1	27.1	21.7	32.6	20.2
May 23 to June 20	29.0	21.9	28.7	22.7	33.1	21.1
June 20 to July 18	27.3	21.4	26.8	22.0	33.9	21.0
July 18 to Aug. 15	26.6	21.4	25.0	22.2	30.0	20.2
Aug. 15 to Sept. 12	26.6	21.2	26.7	21.1	30.9	21.1
Sept. 12 to Oct. 10	26.9	21.1	27.5	21.9	34.6	20.6
Oct. 10 to Nov. 7	25.6	20.7	26.5	20.9	31.2	20.0
Nov. 7 to Dec. 5	24.5	20.0	24.9	19.7	29.4	19.1
Dec. 5 to Jan. 2	24.1	20.0	24.6	20.7	28.4	19.1
Average	26.2	20.7	26.5	20.9	32.1	20.1

Measurements of temperature were also taken with a maximum and minimum thermometer placed in the lower part of the crown of a *Dillenia philippinensis,* a typical second-story tree, and another in the top of a dominant *Parashorea plicata.* The latter thermometer was protected from the sun by means of a perforated wooden box. The maximum and minimum thermometers were read weekly. In Table XLIII these results, together with the weekly maxima and minima from the recording ther-

mometer, are compiled in the form of averages of the weekly maxima and minima for periods of four weeks.

An examination of Table XLIII would seem to show that there is little difference between the temperatures in the undergrowth and in the second story.

The average weekly maximum is 5°.9 higher and the minimum 0°.6 lower in the top of the dominant story than in the undergrowth, while the average weekly range is 12°.0 in the former and only 5°.5 in the latter situation. Since there is but little difference between the minimum temperatures in the two places and the average weekly maximum is 5°.9 higher in the dominant story than in the undergrowth, the dominant story should have the higher average temperature and the one most likely to cause rapid growth. However, this temperature can hardly be regarded as high enough to be optimum for more than a small portion of the time.

The rainfall for the year is given in Table XLIV. It will be seen that the dry season is pronounced, but that it is relatively short, and that there is no month without rain.

Saderra Masó [30] states that the average rainfall for the Archipelago is 240 centimeters. The rainfall in the region under discussion is distinctly less than this. The rainfall in the forest would be classed as seasonal. It is, however, more evenly distributed throughout the year than at most of the weather stations where there are distinct wet and dry seasons.

In Table XLIV there is also given a record of the percentage of soil moisture for the year. The figures are averages of weekly determinations, and the percentages are based on the dry weight of the soil. All samples were taken at a depth of 20 centimeters. The percentage of moisture is always high, and the seasonal changes while pronounced would hardly be called excessive, as the table shows an extreme variation of from 43.2 to 58.2 per cent.

Relative humidity was measured in the forest, at about 75 centimeters above the ground, by a Draper's recording hygrometer. The results are given in Table XLV in the form of maxima, minima, means, averages of daily maxima, and averages of daily minima for periods of four weeks. The means were obtained by using a planimeter. The table shows that the humidity is very high and uniform throughout the year.

[30] Saderra Masó, M. S., Annual amount and distribution of rainfall in the Philippines. Weather Bureau, Manila, P. I. (1914).

TABLE XLIV.—*Rainfall and soil moisture,*[a] *forest of Mount Maquiling, Laguna Province, Luzon.*

Period.	Rainfall.	Average weekly soil moisture.
	cm.	*Per cent.*
Jan. 3 to Jan. 31	5.67	53.3
Jan. 31 to Feb. 28	3.93	48.8
Feb. 28 to Mar. 28	1.87	43.2
Mar. 28 to Apr. 25	1.05	44.5
Apr. 25 to May 23	11.11	46.7
May 23 to June 20	9.21	48.6
June 20 to July 18	26.87	53.2
July 18 to Aug. 15	35.52	54.1
Aug. 15 to Sept. 12	47.35	58.2
Sept. 12 to Oct. 10	8.60	56.2
Oct. 10 to Nov. 7	17.54	55.6
Nov. 7 to Dec. 5	8.88	56.2
Dec. 5 to Jan. 2—14	12.15	55.8
Total	189.75	
Average	14.60	51.9

[a] The record of soil moisture is taken from an unpublished paper by W. H. Brown and A. S. Arguelles.

TABLE XLV.—*Relative humidity in forest of Mount Maquiling, Laguna Province, Luzon.*

Period.	Maximum.	Minimum.	Average.	Average daily maximum.	Average daily minimum.
Jan. 3 to Jan. 31	99.5	85.5	95.6	97.3	92.7
Jan. 31 to Feb. 28	99.0	80.0	93.6	97.3	88.6
Feb. 28 to Mar. 28	100.0	74.0	91.1	98.4	84.2
Mar. 28 to Apr. 25	99.5	68.0	91.4	96.8	81.9
Apr. 25 to May 23	97.5	71.5	92.7	96.4	84.5
May 23 to June 20	97.0	73.5	90.6	94.9	81.2
June 20 to July 18	96.0	82.5	91.5	93.4	87.8
July 18 to Aug. 15	93.5	78.0	89.8	91.5	85.0
Aug. 15 to Sept. 12	95.0	77.0	90.2	92.4	86.6
Sept. 12 to Oct. 10	96.0	79.0	91.5	93.4	86.5
Oct. 10 to Nov. 7	96.0	75.0	92.3	94.4	88.3
Nov. 7 to Dec. 5	97.0	86.0	93.4	95.7	90.5
Dec. 5 to Jan. 2	97.0	86.0	93.9	95.6	92.3
Average	97.2	78.2	92.1	95.2	86.9

Records of evaporation were obtained by means of a Livingston rain-correcting atmometer.[31] The evaporating surface in this instrument is a porous clay cup so connected by means

[31] Livingston, B. E., A rain-correcting atmometer for ecological instrumentation, *Plant World* (1910), **13**, 79–82.

of rubber stopper and glass tube to a water bottle at a lower level that the cup is kept constantly filled, the water evaporating from the moist clay surface being replaced from the bottle. Entrance of rain water around the stopper into the reservoir is prevented by means of an apron of waterproof cloth. The absorption of rain water by the clay cup and the flowing of this water back into the reservoir is effectually prevented by the insertion of a mercury valve between the reservoir and cup, which allows free movement of water from the former to the latter but not in the reverse direction. All readings from the instruments were reduced to the standard used by Livingston. The results are given in Table XLVI in the form of average daily rates for periods of four weeks. The atmometer in the undergrowth was placed 25 centimeters above the ground, the one in the second story was protected by the canopy of both the dominant and second story, while the one in the top of the dominant story was fully exposed to both sun and wind.

The rate of evaporation under the main canopy is low, particularly so near the ground. In the top of the dominant story the rate of evaporation is much higher, being on the average more than six times as great as near the ground. The effect of seasonal changes on evaporation is marked. In the top of the dominant story the daily rate of evaporation for periods of four weeks varies from 8.4 cubic centimeters to 22.1 cubic centimeters.

TABLE XLVI.—*Daily rate of evaporation in forest of Mount Maquiling, Laguna Province, Luzon.*

Period.	30 centimeters above the ground.	In second story tree.	Top of dominant tree.
	cc.	*cc.*	*cc.*
Jan. 3 to Jan. 31	1.4	2.6	8.4
Jan. 31 to Feb. 28	2.5	5.6	15.4
Feb. 28 to Mar. 28	4.2	7.5	20.0
Mar. 28 to Apr. 25	5.3	7.5	19.7
Apr. 25 to May 23	3.6	6.6	18.4
May 23 to June 20	4.9	9.0	22.1
June 20 to July 18	1.6	3.8	13.7
July 18 to Aug. 15	1.7	7.0	20.9
Aug. 15 to Sept. 12	1.2	5.0	16.9
Sept. 12 to Oct. 10	2.1	4.2	15.4
Oct. 10 to Nov. 7	1.6	4.7	13.0
Nov. 7 to Dec. 5	1.2	3.7	11.4
Dec. 5 to Jan. 2	0.7	1.8	8.6
Average	2.5	5.3	15.7

Livingston[32] gives the rates of evaporation at a number of stations in the United States for the period from May 25 to September 7, 1908. He says: "The deciduous forest of the middle east occupies a region with over 100 cc., often over 150 and even 200 cc., as the mean weekly summer rate." These results are not directly comparable with those from Mount Maquiling as they were obtained from atmometers placed 15 centimeters above the ground in the open and with free access to sun and wind. A comparison of the highest rates obtained on Mount Maquiling with those from the United States, however, seems to show that the rate of evaporation from the top of the dominant story on Mount Maquiling is not particularly high even during the height of the dry season. It has already been pointed out that the moisture content of the soil is high at all times of the year. This indicates that conditions in the forest were not excessively dry even at the height of the dry season. It should be remembered, however, that the effect of the dry season on the vegetation is very marked. We have already seen that *Parashorea plicata* shows a very slow rate of growth at this time. The main canopy of the forest, while by no means deciduous, is much less dense during the dry season than at other times, while small herbs may wilt or even dry up completely.

The foregoing discussion of environmental factors in the forest of Mount Maquiling seems to indicate that the conditions were very favorable for the development of a luxurious vegetation and for rapid growth. The forest of Mount Maquiling is very open as compared with a well-developed dipterocarp forest, but is very dense in comparison with a deciduous one of a temperate zone. We have already seen that *Parashorea plicata* grows from 30 centimeters to 70 centimeters in diameter in fifty years, while it takes yellow poplar, the fastest growing temperate-zone species considered in this paper, one hundred fifteen years to make the same growth. This rapid growth is, however, not equaled by smaller individuals of *Parashorea* nor by other dipterocarps where growth has been studied in denser forests. According to our calculations it takes a seedling of *Parashorea* in the forest sixty-two years to become 5 centimeters in diameter. This slow rate of growth is due to the density of the forest, and it is probable that the same conclusion will hold for the

[32] Livingston, B. E., A study of evaporation and plant distribution, *Plant World* (1911), 14, 205.

slow rate of growth shown by trees in denser forests, for while environmental data are lacking for these forests it does not seem likely, nor do our observations seem to show, that these regions which have produced forests denser than that of Mount Maquiling have climates which are naturally less favorable for growth. The density of the forests undoubtedly greatly reduces the amount of light received by all except the largest trees, while at the same time there must be severe competition among the roots of the vegetation. It is to be expected, therefore, that if suitable trees were grown in plantations in such a way as properly to regulate the density the resulting growth would be very rapid. This conclusion is confirmed by the rapid rates of growth shown by *Parashorea* growing in the open and by the even faster development of second-growth trees.

Results which have been obtained in plantation work by the Bureau of Forestry are also in accord with this view.

One of the most striking things about the forest of Mount Maquiling is the great difference between the conditions in the dominant story and in the undergrowth. The most obvious difference is that of light. The dense canopy which cuts down the amount of light entering the undergrowth has a similar effect on the wind, the undergrowth being at most times remarkably still. The fact that comparatively little wind enters the undergrowth probably has a decided effect on the temperature in it. This temperature has a lower average and is much more constant than that in the dominant story. Our records of evaporation show a rate in the top of the dominant story which is, on the average, more than six times as great as that in the undergrowth. These rates, being from white surfaces, do not take into account sufficiently the difference due to sunlight, so that the actual difference between the rates of evaporation in the two situations is even greater than that indicated.

When we consider the differences between the conditions in the undergrowth and in the dominant story, it would not be surprising if plants which had developed in the former were unable to stand the conditions in the latter. When the main canopy is removed, the plants which are left are subjected to conditions at least approaching those to which the dominant story is exposed. We have seen that the removal of the main canopy is usually followed by the death of most of the trees and seedlings which remain. If the only difference between the conditions to which these were exposed before and after the removal of the main canopy was that of evaporation, this alone would probably, in most cases, be sufficient to cause their death.

In very moist localities the effect of removing the main canopy might be much less severe than it would be in the dipterocarp forest on Mount Maquiling.

EFFECT OF CUTTING IN DIPTEROCARP FORESTS

As has been indicated in the discussion of growth, cutting in a dipterocarp forest carries with it a disturbance in the main canopy which is usually accompanied by increased growth and development of the second- and third-story trees, for the most part of inconsiderable commercial value. This holds true, of course, only for unregulated cutting in which the distribution of dipterocarps in the second and third stories is not adequately considered. All cuttings under the supervision of a forest officer or staff are supposed to be done with some attempt at regulation. Where the forest staff is small and has an extremely large area to cover this regulation generally takes the form of a simple diameter limit. The purpose of the diameter limit is so to regulate the amount of cutting that the desirable species remain on the ground in sufficient volume to insure their perpetuation as the dominant species. This system of regulation is essentially a regulation by volume, and in temperate climates, where forests are composed of one or, at the most, of a very few species, it has proved very successful. In the tropics the same measure of success has not, for the most part, been attained. Naturally, some forests are much better suited to the successful operation of such a system than others, but dipterocarp forests are, in a great majority of instances, not among those in which this system succeeds.

The use of the selection system, operated by means of a diameter limit, presupposes that there is in the forest such a distribution of size classes that there can be fixed a diameter limit which will remove that portion of the stand which is ready for cutting and leave on the ground only that portion which should remain. Our dipterocarp forests do not meet this necessary condition. An inspection of the volume table for the northern Negros forest on page 427 shows at once that no diameter limit of any reasonable size will restrict the cutting to only that portion of the main stand which can safely be taken out at one cut. A diameter limit of 50 centimeters is regarded, in most parts of the world, as exceptionally high; but as can be seen from the abovementioned table the operation of such a limit in northern Negros would allow almost clear cutting of the main forest canopy. In the discussion of associations on cleared lands this has been shown to be true. After cutting with a diameter limit of 50

TABLE XLVII.—*Stand of timber on 1 hectare, Bataan Province, Luzon, after cutting.*

[Volumes are given in cubic meters.]

Diameter class.	*Shorea polysperma* (tanguile).		*Dipterocarpus grandiflorus* (apitong).		*Dipterocarpus vernicifluus* (panao).		*Hopea acuminata* (dalindingan).		*Shorea guiso* (guijo).		*Pentacme contorta* (white lauan).		*Anisoptera thurifera* (palosapis).	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
5 centimeters	4	0.0392	6	0.0588			1	0.0098			2	0.0196		
10 centimeters			7	0.274							1	0.049		
15 centimeters	3	0.264	11	0.324										
20 centimeters	2	0.76	8	1.04										
25 centimeters			4	1.08										
30 centimeters	5	1.96	3	1.44										
35 centimeters	1	0.74	2	1.48							1	0.76		
40 centimeters	1	1.07	3	3.24										
45 centimeters			2	3.02										
50 centimeters			1	2.06										
55 centimeters			1	2.69										
60 centimeters														
65 centimeters														
70 centimeters														
75 centimeters														
80 centimeters	1	7.00												
85 centimeters														
90 centimeters	1	9.34												
95 centimeters	2	21.42												
Total	20	42.5932	48	16.7068			1	0.0098			4	0.8286		

Diameter class.	*Eugenia* sp. (macaasim).		*Callophylum blancoi* (palomaria).		*Strombrosia philippinensis* (tamayuan).		Malabayabas.		Miscellaneous trees.		Total volume.	
	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.	Trees.	Volume.
5 centimeters			2	0.0196			1	0.0098	59	0.5782	75	0.7350
10 centimeters			3	0.117			5	0.196	46	0.260	62	0.896
15 centimeters			2	0.127					37	0.727	53	1.442
20 centimeters			1	0.13			5	0.65	17	2.21	33	4.79
25 centimeters			1	0.26			1	0.26	21	5.46	27	7.06
30 centimeters			2	0.88			1	0.44	9	3.96	20	8.68
35 centimeters			1	0.69			2	1.38	4	3.45	11	8.50
40 centimeters							1	1.01	1	1.01	6	6.33
45 centimeters							2	2.84	2	2.84	6	8.70
50 centimeters									1	1.93	2	3.99
55 centimeters							1	2.49	3	7.47	5	12.65
60 centimeters												
65 centimeters												
70 centimeters							1	4.83			1	4.83
75 centimeters												
80 centimeters											1	7.00
85 centimeters												
90 centimeters											1	9.34
95 centimeters											2	21.42
Total			12	2.2236			20	14.1058	200	29.8952	305	106.3630

	Cubic meters.
Trees less than 50 cm. in diameter	47.1330
Dipterocarps less than 50 cm. in diameter	17.6284
Trees more than 50 cm. in diameter	59.2300
Dipterocarps more than 50 cm. in diameter	42.5100

centimeters, the dipterocarp forest is replaced by another of a different type. As an example of what may happen to a forest when such an apparently reasonable diameter limit is applied to a heavy stand of dipterocarp timber, there is here presented Table XLVII for the hectare of timber in Bataan, represented in Table VII, after it has been cut over under a diameter limit of 50 centimeters. These tables are summarized in Table XLVIII.

TABLE XLVIII.—*Comparison of stand of timber on a sample hectare in virgin and logged forest. Bataan Province, Luzon.*

[Numbers show volumes in cubic meters.]

	Uncut forest.	After cutting.	Amount logged off.
Trees less than 50 centimeters in diameter	80.41	47.13	33.28
Dipterocarps less than 50 centimeters in diameter	32.28	17.63	14.65
Trees more than 50 centimeters in diameter	471.49	59.23	412.26
Dipterocarps more than 50 centimeters in diameter	433.69	42.51	391.18
Total	551.90	106.36	445.54

The results presented in these tables indicate that the effect on this forest has not been unduly severe; that is, we have left 106 cubic meters out of an original total of 551, and 42 cubic meters of dipterocarps out of an original total of 433. In temperate regions this would mean that the logging operation had been very successful from the forester's standpoint. In the Philippines the reverse of this is true. A study of the table reveals the fact that the main canopy of the forest has been almost entirely removed, that only 4 dipterocarps above 50 centimeters in diameter remain on the hectare, and that the bulk of the stand numerically lies in the tree classes from 5 to 40 centimeters. With the exception of the 4 trees over 70 centimeters in diameter, all of the stand on the ground has developed entirely under the shade of the main canopy. The result is that these trees have very straggling thin crowns with broad succulent leaves suited only to the conditions which exist under the dense shade of the main canopy. The sudden exposure to full sunlight results in the death of a great majority of the smaller trees within a very short period.

On this same hectare, before cutting, we had on an average plot of 250 square meters a stand of 1,539 seedlings, 1,130 of which were tree seedlings and 409 brush seedlings. Out of the total of 1,130 tree seedlings, 259 were of the family Dipterocarpaceae. After cutting, the number of seedlings on the same area had been reduced to 191, only 38 of which are dipterocarp. The

significance of this astonishing reduction both in the total number of seedlings and in the number of seedlings of dipterocarps is very clear. The destruction of a portion of these seedlings was probably due to mechanical injuries incident to the logging operation. The great majority, however, have died because of the excessive insolation they received during the period just after the main canopy was removed. A discussion of what this change in temperature and atmospheric conditions may amount to has been given in another portion of this paper. The results brought out there show very clearly that the conditions are so changed that seedlings which have developed in dense shade are placed at an immense disadvantage.

As an example of what happens during the period subsequent to logging, Table XLIX is presented, which shows the stand of seedlings on an area of 250 square meters one year after it was logged under the same conditions as those described on page 536. The total number of dipterocarp seedlings in this area is 94. However, 79 of these are of one species, *Pentacme contorta*. This one species alone seems able to exist under the general unsatisfactory conditions incident to a heavy opening of the crown. However, as against the 94 dipterocarp seedlings existing on this 250 square meters, there are 430 seedlings, other than dipterocarps, less than 10 centimeters in diameter, and 435 seedlings of miscellaneous intolerant weeds and vines. It is clear from this that the dipterocarp element will be very inconspicuous in the forest which is developing on this area. On areas logged two years ago there are only 2 dipterocarp seedlings to 25 square meters. As in the case of the northern Negros forest, it has been shown in the discussion of cleared areas that logging in Bataan with a diameter limit of 50 centimeters has resulted, in the past, in the destruction of the dipterocarp forest. In Bataan the forest has been replaced by a bamboo thicket. It may be that at the higher altitudes, about 500 meters, at which the cutting is now being carried on, the moisture or other conditions may make it possible for *Pentacme contorta* to compete with the weed species.

The conclusion to which one is forced, from a consideration of the above data, is that an attempt to limit the cutting in a virgin stand of dipterocarp forest by means of a diameter limit of any reasonable size usually does not limit the cutting at all, but results in a clear cutting operation. This is probably true at least for most areas where intensive utilization is practiced, and where logging is carried on in an intensive manner over large areas.

TABLE XLIX.—*Reproduction on a plot of 250 square meters one year after logging, showing number of plants by species and by diameter class.*

Species.	Seedlings under 2 meters.	Diameter class in centimeters.														Total.
		1	2	3	4	5	6	7	8	9	10	20	30	40	50	
Shorea polysperma (tanguile)																
Dipterocarpus vernicifluus (panao)	6		1													7
Dipterocarpus grandiflorus (apitong)																
Hopea acuminata (dalindingan)																
Pentacme contorta (white lauan)	71	4	2			1	1									79
Shorea guiso (guijo)	7															7
Anisoptera thurifera (palosapis)						1										1
Homalanthus populneus (balanti or maladuron)	14	3	7			2										26
Calophyllum blancoi (palomaria)	33		1													34
Miscellaneous trees	173	4	9	3	2	5	3	2		1	2	2	1	1	1	209
Miscellaneous shrubs	435															435
Euphoria cinerea (alupag)	80	1	3													84
Eugenia sp. (malaruhat)	43	1	1	2	1								1			49
Diospyros pilosanthera (bolongeta)	26	1	1			1										29
Parkia timoriana (cupang)	1	1	4	1												7
Total	889	15	29	6	8	10	4	2		1	2	2	2	1	1	967
Total trees																532
Total dipterocarps																94

	Per cent.
Plants which are trees	55.02
Plants which are dipterocarps	9.72
Trees which are dipterocarps	17.67

The effect of regulation by a diameter limit in a forest less overmature and where logging is more selective than intensive is very different from that just described. In the forest of northern Laguna logging to a diameter limit of 40 centimeters has been carried on, in a desultory manner, for the last fifty or sixty years. The result is very clearly shown by our volume table for this forest, which is presented on page 438. The men who have been logging this region have not been able to use every tree or even every species. They have gone through the forest selecting the medium-sized straight-boled trees of the most desirable species, especially those of *Shorea polysperma* (tanguile), *Dipterocarpus* sp. (apitong), *Hopea pierrei* (dalindingan isak), and a few of the understory trees, such as *Machilus philippinensis* (baticulin) and *Eugenia* spp. (macaasim). They have rarely returned to the same spot in two successive years. The result of their operations has been to change the composition of the forest by a slight reduction in the volume of the species which they have most desired and to change the volume composition of the forest by the removal of the medium-sized and larger-sized trees. The result in regard to volume composition is very clearly shown by our table, and from the forester's standpoint a proper and elastic diameter limit would probably work very successfully. The past success of this limit system for this forest is in part due to the better distribution of age classes and in part to the fact that the logging has not been intensive.

We have now considered a situation where the diameter limit system of regulation has proved an entire failure, and one in which it would probably prove a noticeable success. Between these two extremes we have all gradations. If the diameter limit has been correctly determined, its successful use will depend upon the distribution of the volume throughout the various diameter classes and upon the intensity of the logging. Wherever the volume is grouped in the larger diameter classes, the system will fail, even though the logging is selective. Where there is a uniform distribution of volume in all size classes, it will prove a success if logging is not intensive. Where large investment calls for heavy utilization, an arbitrary limit which permits of the utilization called for by the size of the investment will usually fail over large areas. It will succeed on any large area for that portion of the forest where very small amounts of the larger sizes of trees exist, but will fail in all parts of the forest where a heavy stand of large-sized trees is encountered.

The reason for the failure of the diameter limit in overmature forests over large areas is that the limit approximates clear cut-

ting and the clear cutting extends uninterruptedly over the whole area of the operation. If the system of utilization is necessarily so intensive that it becomes impossible to leave the necessary amount of shelter wood in the area, it will be better to abandon entirely any thought of limitation of the cut and to accept as inevitable the fact that clear cutting will have to be carried on and then so to regulate this clear cutting that a fair measure of success can be expected. Due to environmental considerations clear cutting in the Philippines will probably rarely be a satisfactory system of forest management. The intense insolation following any considerable opening of the forest crown is always followed by a tremendous reduction in the percentage of the main species in the reproduction and by the entrance of vast quantities of intolerant, rapid-growing weeds, trees, and vines. The larger we make the opening in the forest, the greater is the change in the climatic condition and the more surely does the forest pass over into a second-growth or jungle habit. If then clear cutting becomes necessary, it must be confined to the smallest possible area permissible under the system of logging in use. The smaller the opening in the forest, the more does the effect of the adjoining forest extend over it and, likewise, the less is the opportunity for light-loving weeds and vines of the adjoining open land to enter the area. If the system of utilization is not so intensive as to preclude the possibilities of leaving on the area a shelter wood which will at the same time protect the young growth already on the ground and furnish seeds for additional reproduction, some system of limiting the cutting is advisable. The defect of one arbitrary diameter limit for the whole area has already been discussed. If the amount of supervision that can be given the operation is so limited that it becomes obvious that nothing but a diameter limit can be used for purposes of regulation, the limit should vary for each of the main species in the area. No diameter limit whatever should be set until after a thorough study of the volume and species distribution of the forest has been concluded and until there have been collected data showing the approximate size at which most of the main species come into full seed bearing. With data of this kind at hand it would be possible to set a diameter limit for each of the species in the stand which would be satisfactory for certain limited types of forest. It would not be possible to set such limits for each species, over the entire area, as the habit of growth of the trees, their time of seeding, and distribution by volume will differ at different elevations and under different conditions of soil moisture and exposure. A study should,

therefore, be made of these conditions for every locality in the forest in which a given set of forest conditions and distribution by volume exists.

While the above-outlined system for the setting of a diameter limit will, in most instances, result in a fair measure of success from the management standpoint, it is by no means sufficiently elastic to meet entirely the conditions both of utilization and of reproduction. Even if the localities for which the different sets of diameter limits are constructed are very small, there will be places in these localities whose conditions are not met by the given diameter limits; in such areas the loggers will be forced to leave trees, at a very considerable financial loss, which could just as well be removed or they will be permitted to remove trees necessary for the reproduction of the forest and, perhaps, not as valuable for timber as some of the trees retained on the area by the diameter limit.

The next step in advance of any diameter-limit regulation is the shelter-wood system properly applied by an intelligent forest officer who marks the timber for removal. The forest officer in charge of such an operation should take into consideration with regard to every tree that he marks all the factors of reproduction, including climatic conditions, rates of growth of the different species, the age at which each species produces its greatest amount of seed, and species composition of the forest, and also the utilization problem which must be met by the loggers. An intelligent forest officer who has an appreciation of these factors of utilization and reproduction is able to adjust the differences in demand between the two, so that neither does the forest suffer unduly for the lumbermen's advantage nor the lumbermen in the interests of the forest and its reproduction. In all but the most overmature and unsatisfactory forests, from the standpoint of management, such an officer can make the needs of the lumbermen serve those of the forest and actually improve the forest both as to composition and rate of growth by the logging operation.

PLANTING

As has been indicated in other portions of this paper, the planting of dipterocarps on any large commercial scale is impracticable at the present time. This is due chiefly to environmental considerations. In few places in the Philippines are there found conditions so suitable to forest trees that they can be planted directly in the area and come to maturity without the most serious competition with other species of plants which are

better suited to the conditions. This is probably truer of dipterocarps, which in youth require shade and moisture and are of relatively slow growth, than of many other species. Likewise, it is truer on grasslands and in the open than in second-growth areas or in openings in a high forest. Plant associations on cleared land throughout the Islands have already been discussed, and it has been shown very clearly that the conditions which exist on cleared lands, especially if those lands are of considerable extent, are most unsuitable to species of the family Dipterocarpaceae.

PLANTING IN GRASSLANDS

Attempts at the direct installation of dipterocarps in grass areas must be expected to meet with failure. The moisture conditions which exist in grasslands are unfavorable, while the competition with the grass, with its dense mass of underground stems, is greater than any dipterocarp which has so far been studied can withstand. It is probable that only one of the dipterocarps growing in the forests discussed in this paper would show as much as 1 per cent living at the end of a year, if planted directly in such situations. This one exception which might meet with some measure of success is *Pentacme contorta* (white lauan), several seedlings of which have been found growing in open second-growth areas. But taking into consideration the high death rate of such species as *Pterocarpus indicus* (narra), *Vitex parviflora* (molave), and *Albizzia procera* (acleng-parang), which are among the species most suited to these conditions, it is doubtful if even white lauan could succeed, and it is certain that from a practical standpoint such planting of most dipterocarps would be a failure. If it ever becomes desirable to reforest grasslands with dipterocarps, cultural operations leading to the establishment of a second-growth forest must be undertaken first.

PLANTING IN SECOND-GROWTH FORESTS

The conditions in second-growth forests are very much closer to those in high forests than are the conditions in grass areas. The upper layers of the soil are not completely filled with underground stems of grasses, which make the competition for such soil moisture as is available too keen for the existence of broad-leaved, tender dipterocarp seedlings, and the crowns of the second-growth trees, while not exceptionally dense, are sufficient to prevent the rapid drying of the surface of the soil in the first

two or three days of sunny weather. Where second-growth species occur in sufficient density to prevent the establishment of a thick ground cover of succulent grasses and herbs, the mineral soil is often sufficiently moist to furnish a fairly satisfactory seed bed for some dipterocarp species. Such satisfactory conditions are sometimes found where pure stands of *Homalanthus populneus* or *Trema amboinensis* exist in moist regions. On burned-over areas at high elevations within the recent logging area on Mount Mariveles, Bataan, such stands of *Homalanthus* are claiming large areas. This species does not produce such a dense crown cover as to prevent the development of seedlings once they are established, and seedlings of *Pentacme contorta* (white lauan) have been found entering such areas to an extent of 1 to each 25 square meters within six months after the area has been logged over. These areas of *Homalanthus* thus give some promise of going over to a stand of *Pentacme contorta* within a short period if *Homalanthus* is able to maintain itself, as *Pentacme* seedlings under such conditions grow at a very rapid rate for dipterocarps. It must be said, however, that *Pentacme contorta* is the only species of dipterocarp in Bataan which has shown the ability to seed in second-growth forests. Although no other species of dipterocarp has been found entering such areas, it must be remembered that the white lauan has established itself by seeds alone. Since this species is able to seed in naturally, it seems reasonable to expect that other dipterocarps could be planted in the area with success.

With most of our dipterocarps the rate of growth in youth under the second-growth conditions, which are necessary to make growth possible, is so slow and the cost of seed collection and of the establishment of plantations is so great that from the standpoint of a commercial planting operation the financial returns which could be expected would not warrant the investment. In general, it is safe to say that if planting operations are conducted in the Philippines at all the species chosen must be ones like *Tectona grandis* (teak), *Pterocarpus indicus* (narra), or *Vitex parviflora* (molave), which have already given a fair measure of success in plantations and which are more suited naturally to the conditions existing in the areas to be reforested. Also, species such as these produce timber of a greater value than do the dipterocarps and apparently grow more rapidly; therefore, more money can be spent in the establishment of the plantations with the expectation of a reasonable return on the investment.

GENERAL CONSIDERATIONS OF MANAGEMENT

It is not within the scope of this paper to enter into a discussion of the details of forest management for any particular area, nor are the data which would permit this at hand. It is possible, however, to conclude our discussion of dipterocarp forests with some general conclusions, and with these conclusions as a basis to outline the broad principles of management for each of the main types of forest here discussed. Upon these as a basis there can be built up detailed methods or working plans.

The conclusions with regard to the management of our dipterocarp forests may be summed up as follows:

(1) From a management viewpoint, dipterocarp forests carrying the heaviest stand per hectare present the most serious problems. (2) Those dipterocarp forests in which the dipterocarps have been able to dominate the stand and exclude the major portion of species of other families, without at the same time developing into a one-storied forest, present the easiest problems from the management standpoint. (3) Those forests in which the second and third stories have achieved undue prominence, due to the action of man in opening the canopy, are very difficult of management. (4) While Philippine forest trees, growing in the open, often show more rapid growth than forest trees in the temperate zone, the growth of individuals in virgin forests is not as great as the growth of individuals in temperate virgin forests, except in the higher diameter classes, and the total volume production per hectare per year in Philippine forests is probably less than that in temperate hardwood forests. (5) The maintenance of a fairly dense shelter wood is necessary for the satisfactory reproduction of most dipterocarp species. (6) Clear cutting on large areas will prove a failure in nearly all instances, and if clear cutting must be undertaken it should be confined to the smallest practicable unit of area. (7) A large majority of our dipterocarp forests, which apparently contain a very heavy stand per hectare, are often much reduced in volume, due to the presence of defects, and are either equally balanced between growth and decay or are actually deteriorating if decay is progressing more rapidly than growth. (8) Successful management of dipterocarp forests will depend upon (*a*) a thorough understanding of the effects of environmental factors on reproduction and growth, (*b*) accurate data as to the distribution of volume throughout the various size classes, (*c*) a knowledge of the various sizes at which the different species of the dipterocarps begin to produce seeds, and

(*d*) accurate data concerning the rate of growth of each species.

The application of these conclusions to the problem of management presented by the various forests which have been discussed in this paper may now be briefly considered. Taking up first the forest of northern Negros, which probably presents as difficult a problem as any dipterocarp forest in the Islands, we find the problem to be that of removing within the shortest possible rotation a large amount of accumulated wood capital which is not producing, but is perhaps deteriorating due to fungus and insect attack and which is, nevertheless, so integral a part of the forest that its removal endangers the very existence of the forest.

One of the chief difficulties which stands in the way of satisfactory management of such a forest is a utilization difficulty; and this is due to the large size of the trees, which makes steam appliances necessary for the removal of the crop. Steam logging calls for large investment per unit of area, and to pay interest on this investment and leave a reasonable profit for the investor a large amount of timber per hectare must be removed. In order to meet this necessary demand on the part of the investor, such forests have in the past been regulated by a 50-centimeter diameter limit in the hope that such a diameter limit would allow the lumberman to remove the amount of timber necessary to give him a return on his large investment and at the same time retain sufficient timber on the ground to maintain forest conditions and insure reproduction. The results have not been satisfactory, and instead of having a regulation which leads to the limitation of the cutting we have had practically a system of clear cutting without any regulation whatever.

The utilization problem, together with the necessity of removing the large amount of timber which has accumulated on the ground and is past maturity and which in the future will become less and less valuable, seems to indicate that clear cutting will be the only system which can be practiced. Were the planting of dipterocarps a practical proposition, a clear-cutting and planting system would be preëminently the most desirable. Planting is, however, entirely out of the question, and likewise any of the systems which call for the existence, after logging, of a shelter wood over the entire area seems impracticable. Clear cutting with natural reproduction from the side seems to hold out some promise of success.

We may, therefore, consider what form of clear cutting will prove the least disastrous to our forest. The clear cutting over large areas, which has followed the application of an erroneous diameter limit, has already proved an entire failure. This has

been due to the sudden and complete change of forest conditions which has followed the removal of the main canopy. The solution of the problem presented by the clear-cutting system under such conditions is to restrict the area of cutting to the smallest limit possible with the methods and appliances of utilization in force in the area. In other words, a system of clear cutting in strips where the strips are, if possible, less than twice the height of the trees is indicated as the most satisfactory system of management under the existing conditions.

From the management standpoint the removal of only a portion of an overmature forest, such as this, is unsatisfactory, in as much as that part of the timber which is left will have to remain on the ground for a large portion of the succeeding rotation and will, therefore, deteriorate and in certain places possibly be an entire loss. It should be possible, however, to remove the bulk of the stand at the first cut. Satisfactory conditions of reproduction might be obtained if openings in the forest were confined to strips running perpendicular to the direction of the prevailing wind, provided these strips were not more than 200 meters in width. The intervening strips of forest which are left on the ground should not be less than 100 meters in width. Following out a system such as this, two-thirds of the stand could be removed at the first cut, and with care in the location of the strips it should be possible to locate the areas to be cut in situations where the greatest overmaturity exists. It would not be advisable to adhere closely to one standard width of strip, but this should vary with the composition of the forest, slope of the land, known rate of growth of the trees, and distribution of the stand by volume throughout the various size classes. Thus, in Negros, species such as *Shorea negrosensis* (red lauan) and *Shorea eximia* (almon) show themselves better able to reproduce under open conditions than do *Shorea polysperma* (tanguile or balacbacan) and *Dipterocarpus grandiflorus* (apitong). Wherever the bulk of the stand is composed of the first two species, it would be possible to make the strips wider than the average, while where the other species predominate it might be necessary to restrict cutting to narrower strips. Where it is possible to locate the strips for cutting in broad gulches bordered on each side by well-wooded hills, the strips might be made twice the width of the average, while the forest on the tops of the ridges should never be removed, unless it is absolutely necessary. If this system were put into practice, a careful study of the conditions in the openings so made should follow the cutting, and the later

application of the system should vary in accordance with the data thus collected.

As has been pointed out the conditions which exist in the dipterocarp forest of Bataan Peninsula differ from those of the northern Negros forest in that the stand is less heavy, the volume distribution by size classes more satisfactory, and the composition of the forest more complex. Furthermore, the topography, consisting of a series of radiating steep ridges separated by rather narrow valleys, is a great disadvantage from the logging standpoint. Clear cutting in strips on this area might be successful in certain patches of the forest where exceptional overmaturity exists, but in the main the logging difficulties which will arise in the application of such a system make it inadvisable. On the other hand, the more uniform distribution of volume through the different size classes, the presence of adequate reproduction on the ground in virgin stands, and the presence of distinct second and third stories make the possibility of some modification of the shelter-wood system worth considering. In applying the shelter-wood system to mature and overmature stands, an attempt is made to remove the bulk of the mature and overmature timber within a restricted period and to replace it with a new, more or less even-aged stand which develops uniformly over the logged area under the shelter of a portion of the stand which is left on the ground. This system, when practiced in temperate zones, aims to remove all of the mature and overmature timber, leaving on the ground only the most thrifty and rapid-growing trees. To meet the problems of utilization, this system will have to be modified for use here. The most overmature timber in our forest is often so defective that it can only be logged out at an actual loss, and the timber which composes the bulk of the second and third stories is not marketable. The timber that it is possible to log at a profit is exactly the portion of the stand which from the forester's standpoint would be most desirable to retain on the ground. In the practice of this system here, the forester is compelled to resort to the expedient of removing the best timber in his forest and of leaving on the ground for his shelter wood his second and third stories, with such overmature specimens of his main species as are too defective to prove of value commercially. These last may be used as seed trees. Were it not for the very satisfactory stand of dipterocarp seedlings existing in the ground cover, the system would hold out but little promise of success, as the seeds distributed from the overmature trees which it is possible to leave would probably not be sufficient to insure the

proper representation of dipterocarps in the new stand. However, with careful logging, leaving a shelter wood for the most part of species other than dipterocarp, it is possible to leave the forest after logging with a stand of seedlings on the ground averaging at least 1 dipterocarp to every 4 square meters and to leave at the same time a shelter wood sufficiently dense to insure the development of these seedlings into a new crop.

As with the clear-cutting system recommended for the forest of Negros, it is, of course, impossible to formulate at this time any detailed rules for the application of the shelter-wood system under the conditions just described. The factors of reproduction are rarely found uniform over large areas in virgin forests, and the application of the system must necessarily vary to meet these changes in the factors of reproduction. In certain portions of the forest of Bataan, it will be found that the representation of dipterocarps in the main stand is much less than that of second-story trees, which, due either to logging in the past or to conditions especially suited to their development, have achieved dominance. Where conditions such as these exist, it will be necessary to prohibit almost entirely the cutting of dipterocarps and to allow only the removal of such individuals of the second story as the loggers think can be removed at a profit. Such an operation as this should result in the improvement of the composition of the new stand over the one which exists at present. In other places, it will be found that the whole of the forest consists of a stand of thrifty rapid-growing species of dipterocarps; in these the shelter wood will have to be composed of timber having a very distinct market value at the present time and which, when left on the ground, causes a very distinct loss to the loggers.

However, over the greater portion of the area it will be found that it is possible to leave a proper representation of dipterocarps in the shelter wood by leaving only the most overmature and defective specimens, without any serious reduction in the profits of the logging operation and without any great economic loss due to the deterioration of timber which is of value at present, but which will become valueless before the time of the second cut.

The successful practice of the shelter-wood system in any forest in the Philippines calls for actual timber marking by a trained forest officer. Experiments leading to the establishment of this system in the forest of Bataan are already under way, and hold out a very fair promise of success. Some 10 hectares of forest have already been logged, and the bulk of the market-

able portion of the crop has been removed. The forest remaining appears to be in a condition which assures satisfactory reproduction. Plate XIII is a view taken of a portion of this forest after all logging operations have been completed. As will be noted from this view, a very fair shelter wood of species of the second and third stories remains on the ground, while on the left may be seen the trunks of 2 individuals of the main story, which being defective have been left for seed distribution. The large trees at the left of the picture are overmature specimens of *Shorea polysperma*. Such trees, while they produce large quantities of seeds and shelter the ground very effectively, are absolutely worthless for timber, and their retention as a portion of the shelter wood occasions no loss whatever. The objections which could be raised to the practice of retaining trees such as these in the shelter wood are that they might disseminate fungous spores and that the seeds furnished by them might be of less desirable quality than those from more thrifty, rapid-growing individuals. However, the latter point is one which has never been proved. The defect which exists in these trees, rendering them valueless for timber, is acquired and is probably not hereditarily transmissible. Such trees have passed through all the stages incident to the existence of the species in the stand, and are now in the last stages of existence due to excessive fungous attack. They produce seeds in large quantities, and although the seeds may possibly be less fertile than those produced by younger trees there is no reason to believe that such of these seeds as germinate will produce trees more subject to fungous attack than trees which develop from seeds of the same species in younger stages of development.

In the discussion of the forest of northern Laguna, the regular distribution of volume through the various size classes and the presence of very dense reproduction in the ground cover and in the second and third stories of the forest make the problem of management very simple indeed. Either of the systems discussed above would probably prove successful here. The climate is so pronouncedly that of the nonseasonal belt, and the composition of the forest so simple, that clear cutting in patches or strips would probably result in a heavy reproduction of dipterocarp species. Likewise, the dense reproduction and large volume representation in the lower diameter classes would permit of the practice of the shelter-wood system, with the shelter wood composed mainly of thrifty, rapid-growing dipterocarps. The forest is also eminently suited to the practice of the selection system with a proper diameter-limit regulation. This is

proved by the fact that the forest has undergone rather severe logging under this system without in any way losing its dipterocarp character and without appreciably reducing its volume production.

In the management of this forest, there are three systems from which the forester can choose the one most suitable to the system of utilization which is to be practiced. While, as stated above, it is possible for him to apply a clear-cutting system, it is not probable that any utilization conditions would demand that such a system be installed. The timber is not large enough to necessitate the installation of expensive steam machinery for the exploitation of the forest. And even if a company desiring to use steam machinery should log the area it would not desire to cut clean, as a large percentage of the volume lies in trees of sizes which it could not utilize. If a large logging operation were attempted in this forest, the shelter-wood system would seem distinctly the most advisable. With this system, it would be possible to remove all of the mature and overmature timber and even a portion of that which has not as yet attained maturity and still leave the forest in a condition which would insure the development of a dense, even-aged stand composed largely of dipterocarp species. The application of the diameter limit of 50 centimeters would, over most parts of the area, if logging were complete, result in a shelter wood on the ground after logging which would be all that could be desired. Naturally, however, much better results could be obtained were the shelter-wood system practiced under the supervision of a trained forest officer and the trees for removal marked by him, after taking into consideration the factors of reproduction for each locality.

MOUNT MAQUILING

As has been indicated in the discussion of the forest at present existing on the lower slopes of Mount Maquiling, this forest is typical of over-cut areas throughout the Islands. The dipterocarp element has been reduced to a subordinate place in the composition of the forest, with regard to both species and volume composition. This result has come about through many years of very selective logging, and all of the forest from the edge up to 300 or 400 meters in elevation presents a condition most difficult from the standpoint of management. According to Whitford, there are about 51,800 square kilometers (20,000 square miles) where conditions similar to those above described obtain. The quickest and most successful method of bringing

this over-cut forest into a normal condition would be to underplant the entire area with either dipterocarps or other species more suitable to planting operations. However, planting on such a large scale is entirely out of the question at the present time, and we must look to cultural operations in the forest itself for the improvement of conditions. The bulk of the timber on the ground at present is not of the species which we desire to see in this forest when it again becomes fully stocked, and the dipterocarps which would normally exist in the area are present in such small amounts, with the exception of *Parashorea plicata,* that there seems little chance of obtaining a satisfactory stand of these species within one or two rotations. The chief obstacle in the way of cultural operations leading to the reproduction of a pure or nearly pure stand of dipterocarps is that the timber market is such that many of the species now existing in the area cannot be disposed of at a profit. Were the market willing to accept timber of the miscellaneous qualities which this forest is at present capable of producing, it would be possible so to cut over the forest that the dipterocarp element would become much more pronounced at the end of one rotation of seventy or eighty years, and it would be possible to attain a fairly dense stand of dipterocarps by the end of a second similar rotation. The procedure to be followed would be that of the shelter-wood system, the shelter wood itself being composed of species for the most part other than dipterocarps, but containing also a fair representation of *Parashorea plicata.* It would be necessary to remove large amounts of timber of miscellaneous species from the present first and second stories, thereby admitting light to the suppressed stand of dipterocarp seedlings and saplings which exist in the lower stories of the forest. This opening of the main canopy would have to be carried out under very strict technical supervision, in order that every one of the groups of dipterocarps now on the ground might be retained without serious reduction in amount due to competition of weeds and vines and valueless trees of the lower stories. In other words, the forester would have to base his system of cutting upon the needs of the dipterocarp reproduction on the ground, regardless of the financial side of the logging operation, and would have to forego a large part of present returns in the interest of improving the composition of this forest. Where labor is cheap, as in India, such cultural operations are often carried on under the name of "cleanings." In the more valuable teak forests of India they may go even further than this and cut trees infested

by strangling figs, and all trees of undesirable species which are hindering the development and reproduction of the desired species. Unless the market becomes less selective in the Philippine Islands, such operations will never be financially successful here. Even when the demand for timber becomes much greater here than it is at present, it will probably be impossible to carry on such operations anywhere except in forests located near large centers of population where timber of any size or quality can be utilized. Due to financial considerations, we cannot at present make any considerable attempt toward active management of this vast area of low-grade forest. The best that can be done for this forest for the next fifty or one hundred years is adequately to protect it both from fire and further overcutting, restricting all cutting of the species with which it is desired to reforest the area and confining such cutting as is necessary to species of the lower stories. Such protection and stringent cutting regulations will lead to the improvement of the forest and bring it into a much better condition for rational management when this becomes possible in later years.

In the forest above 300 meters on Mount Maquiling and extending to an altitude of 600 meters we have a forest in which conditions are about intermediate between the virgin forest of Bataan and those of the lower portion of the forest on Mount Maquiling. Here management is very necessary, and can accomplish immediate results. The dipterocarp type is usually not so pronounced in such areas, but dipterocarps grow here mixed with second-story and third-story trees of considerable value. The system of management to be recommended is that of the selection system carried on under the supervision of a trained forest officer. The forest officer in charge of such an operation should be thoroughly acquainted with the silvicultural requirements of all of the important species of his forest, their age of seeding, rate of growth, and other similar data. Trees for removal should be marked in accordance with the demand of the species, and no attempt should be made to regulate such a forest, which is necessarily of a very mixed character in regard to distribution both by volume and by species, by one arbitrary diameter limit.

SUMMARY

1. The dipterocarp forest is the most extensive and important lowland forest of the Indo-Malayan region.

2. In the Philippines it would naturally occupy all of the best sites, but owing to the combined influence of man and climate

it has been removed from considerable areas. This is especially the case in regions in which the dry season is pronounced.

3. Due to the fact that the forest occurs in dense stands of a few species which may be logged at a low cost, it is capable of furnishing large amounts of construction and finishing lumber.

4. The chief difference between the dipterocarp forest and a hardwood forest of the temperate zone lies in the several-storied arrangement of the dipterocarp forest, with an accompanying greater density of foliage, and in the presence of a much larger number of minor tree species.

5. Dipterocarp forests vary from dense stands in which the main story is composed entirely of mature and overmature dipterocarps to more open stands in which the main canopy may contain more individuals of other species than dipterocarps.

6. The volume of a dipterocarp forest may be greater than that of an all-aged managed stand in Europe, but is usually less. When the volume is great its distribution is usually unsatisfactory from a management standpoint, as the bulk of it is contained in large mature and overmature individuals, the removal of which causes the destruction of the forest.

7. If the dipterocarp forest is removed and the land is not cultivated, the forest is replaced by a noncommercial one of a totally different type in which the trees are small, softwooded, rapidly growing species. If, after the removal of the forest, the land is cultivated and later abandoned, it usually grows up in grass which maintains itself as long as it is burned over at more or less frequent intervals.

8. Dipterocarps growing in virgin forests in the Philippines undergo an extremely long suppression period. After this suppression period *Parashorea plicata,* the most rapidly growing dipterocarp measured, appears to grow about twice as fast as yellow poplar in virgin stands. The average of the dipterocarps measured shows rates of growth, after the suppression period, about equal to those of hardwoods in virgin forests in the central hardwood region of the United States. *Parashorea plicata,* on Mount Maquiling, shows distinct seasonal rates of growth, there being two periods of slow and two of rapid growth. One period of slow growth coincides with the dry season, the other with the height of the rainy season when the sky is overcast for a large portion of the time.

9. The temperature in the dipterocarp forest of Mount Maquiling is very uniform and not particularly high. The daily range is much greater in the dominant story than in the undergrowth.

The humidity and soil moisture under the forest are always high and the rate of evaporation is low. The environment of the dominant story is much dryer than that of the undergrowth. The rate of evaporation, even in the top of the dominant story during the dry season, is not high when compared with evaporation rates in deciduous forest regions in the United States. Environmental conditions in the forest are apparently favorable for growth throughout the year. The result is that such a dense vegetation is produced that the rate of growth of the individuals is greatly lowered.

10. The total growth of whole forests in the Philippines will in many instances be greater than that in a temperate hardwood forest, but the volume production of commercial timber will usually be lower.

11. Clear cutting over large areas will, in most instances, eliminate dipterocarp species from any forest. Clear cutting on small areas will, in many instances, result in a satisfactory stand of dipterocarp reproduction. Selective cutting and culling, if not severe, will merely lower the volume production without seriously changing the species composition, but if continued over long periods will result in the elimination of all dipterocarp species which are cut. A partial cutting followed by a long period of closure seems to be the most satisfactory method of cutting over a dipterocarp forest.

12. Present experience seems to indicate that planting of dipterocarps will not be successful in open lands and probably only moderately successful in second-growth forests or in openings in the high forest. If planting is to be attempted in the Philippines at the present time, species which are easier to handle than dipterocarps and more valuable at maturity should be chosen.

13. Heavy stands of dipterocarp forest which are largely overmature will have to be managed under some modification of the clear-cutting system. Those which contain distinct second and third stories composed partially of dipterocarps and partially of miscellaneous species can be most successfully managed under the shelter-wood system. Those in which there is a satisfactory distribution of dipterocarps throughout all size classes can be satisfactorily handled under either the shelter-wood system or the selection system with a diameter limit. Those which have been very heavily cut over under a diameter limit that was too low should be protected from all cutting until the small dipterocarps in the lower stories become large enough to bear seed.

SCIENTIFIC AND LOCAL NAMES OF THE PLANTS MENTIONED IN THIS PAPER AND THE FAMILIES TO WHICH THEY BELONG

Acacia farnesiana Willd. (aroma). Leguminosae.
Aglaia diffusa Merr. (salaquin pula). Meliaceae.
Aglaia macrobotrys Turcz. (malatumbaga). Meliaceae.
Alangium meyeri Merr. (putian). Cornaceae.
Albizzia procera Roxb. (acleng-parang). Leguminosae.
Albizzia acle Merr. (acle). Leguminosae.
Albizzia saponaria Blume (salinkugi). Leguminosae.
Alstonia macrophylla Wall. (batino). Apocynaceae.
Alstonia scholaris R. Br. (dita). Apocynaceae.
Anisoptera thurifera Blanco (palosapis). Dipterocarpaceae.
Antidesma bunius Spreng. (bignay). Euphorbiaceae.
Antidesma edule Merr. (malatumbaga pula). Euphorbiaceae.
Antidesma ghesaembilla Gaertn. (binayuyu). Euphorbiaceae.
Aphananthe philippinensis Pl. (alasiis). Ulmaceae.
Aporosa microcalyx Hassk. Euphorbiaceae.
Ardisia boissieri A. DC. (tagpo). Myrsinaceae.
Ardisia perrottetiana A. DC. Myrsinaceae.
Artocarpus communis Forst. (antipolo). Moraceae.
Asplenium nidus Linn. Polypodiaceae.
Baccaurea tetrandra Baill. (dilac). Euphorbiaceae.
Bauhinia malabarica L. (alibangbang). Leguminoseae.
Biophytum sensitivum DC. Oxalidaceae.
Bischofia javanica Bl. (tuai). Euphorbiaceae.
Blumea balsamifera DC. (sambong). Compositae.
Bombax ceiba L. (malabulac). Bombycaceae.
Buchanania florida Bl. (balinghasay). Anacardiaceae.
Callicarpa erioclona Schauer. Verbenaceae.
Calophyllum blancoi Pl. and Tr. (palomaria del monte). Guttiferae.
Calophyllum cumingii Pl. and Tr. (palomaria). Guttiferae.
Canangium odoratum Baill. (ylang-ylang). Anonaceae.
Canarium luzonicum A. Gray (pili). Burseraceae.
Canarium villosum F. Vill. (pagsahingin). Burseraceae.
Carallia integerrima DC. Rhizophoraceae.
Celtis philippensis Blanco (malaicmo). Ulmaceae.
Champereia manillana Merr. Opiliaceae.
Chisochiton cumingianus Harms (salaquin puti). Meliaceae.
Chisochiton philippinus Harms (catang macsin or salaquin pula). Meliaceae.
Chisochiton tetrapetalus DC. (catang macsin). Meliaceae.
Cinnamomum mercadoi Vid. (calingag). Lauraceae.
Cissus trifolia K. Sch. Vitaceae.
Citrus hystrix DC. (cabuyao). Rutaceae.
Clausena anisum-olens Merr. (cayatana). Rutaceae.
Clerodendron quadriloculare Merr. Verbenaceae.
Columbia serratifolia DC. (anilao). Tiliaceae.
Commelina nudiflora L. Commelinaceae.
Cryptocarya lauriflora Merr. Lauraceae.
Cyathocalyx globosus Merr. (latuan). Anonaceae.
Cyclostemon bordenii Merr. (talimorong or diladila). Euphorbiaceae.

Cyclostemon microphyllus Merr. (talimorong). Euphorbiaceae.
Desmodium pulchellum Benth. Leguminosae.
Dillenia reifferscheidia F.-Vill. (catmon). Dilleniaceae.
Dillenia philippinensis Rolfe (catmon). Dilleniaceae.
Diospyros discolor Willd. (camagon). Ebenaceae.
Diospyros pilosanthera Blanco (bolongeta). Ebenaceae.
Diplodiscus paniculatus Turcz. (balobo). Tiliaceae.
Dipterocarpus grandiflorus Blanco (apitong). Dipterocarpaceae.
Dipterocarpus tuberculatus Roxb. Dipterocarpaceae.
Dipterocarpus vernicifluus Blanco (panao). Dipterocarpaceae.
Dracontomelum cumingianum Baill (lamio). Anacardiaceae.
Dracontomelum dao Merr. and Rolfe (dao). Anacardiaceae.
Ellipanthus luzoniensis Vid. Connaraceae.
Eugenia cumingii Vid. Myrtaceae.
Eugenia glaucicalyx Merr. (mareeg). Myrtaceae.
Eugenia luzonensis Merr. (malaruhat puti). Myrtaceae.
Eugenia mananquil Blanco. Myrtaceae.
Eugenia similis Merr. (malaruhat). Myrtaceae.
Eugenia tripinnata C. B. Rob. Myrtaceae.
Eugenia whitfordii Merr. (malaruhat). Myrtaceae.
Euphoria cinerea Radlk. (alupag). Sapindaceae.
Eulophia exaltata Reichb. f. Orchidaceae.
Euonymus javanica Bl. Celastraceae.
Ficus ampelos Burm. (malaisis). Moraceae.
Ficus barnesii Merr. Moraceae.
Ficus hauili Blanco (hauili). Moraceae.
Ficus minahassae Miq. (hagimit). Moraceae.
Ficus nota Merr. (tibig). Moraceae.
Ficus ribes Reinw. (aumit). Moraceae.
Ficus variegata Blume (tangisang biawak). Moraceae.
Garcinia binucao Choisy (binucao). Guttiferae.
Garcinia rubra Merr. Guttiferae.
Garcinia venulosa Choisy (gatasan). Guttiferae.
Glochidion lancifolium C. B. Rob. Euphorbiaceae.
Goniothalamus elmeri Merr. Anonaceae.
Gonocaryum calleryanum Becc. (malasamat). Icacinaceae.
Gordonia fragrans Merr. Theaceae.
Grewia stylocarpa Warb. (susumbik). Tiliaceae.
Gymnacranthera paniculata Warb. (tambalao). Myristicaceae.
Homalanthus populneus Pax (balanti). Euphorbiaceae.
Hopea acuminata Merr. (dalindingan). Dipterocarpaceae.
Hopea pierrei Hance (dalindingan-isak). Dipterocarpaceae.
Illipe ramiflora Merr. (baniti). Sapotaceae.
Imperata exaltata Brongn. (cogon). Gramineae.
Ipomoea triloba L. Convolvulaceae.
Ixora longistipula Merr. Rubiaceae.
Ixora macrophylla Bartl. Rubiaceae.
Koordersiodendron pinnatum Merr. (amuguis). Anacardiaceae.
Knema heterophylla Warb. (tambalao). Myristicaceae.
Kopsia longiflora Merr. Apocynaceae.
Lagerstroemia speciosa Pers. (banaba). Lythraceae.
Laportia subclausa C. B. Rob. (lipa). Urticaceae.

Leea aculeata Blanco. Vitaceae.
Leea manillensis Warb. Vitaceae.
Leea philippinensis Merr. Vitaceae.
Leucosyke capitellata Wedd. (lagasi). Urticaceae.
Litchi philippinensis Radlk. Sapindaceae.
Litsea garciae Vid. Lauraceae.
Litsea glutinosa C. B. Rob. (puso-puso). Lauraceae.
Lophopetalum toxicum Lober (kalatumbago). Celastraceae.
Macaranga bicolor Muell.-Arg. (hamindang). Euphorbiaceae.
Macaranga grandifolia Merr. (taquip asin). Euphorbiaceae.
Macaranga tanarius Muell.-Arg. (binunga). Euphorbiaceae.
Machilus philippinensis Merr. (baticulin). Lauraceae.
Mallotus moluccanus Muell.-Arg. (alim). Euphorbiaceae.
Mallotus philippensis Muell.-Arg. (banato). Euphorbiaceae.
Mallotus ricinoides Muell.-Arg. (hinlaumo). Euphorbiaceae.
Mangifera altissima Blanco (pahutan). Anacardiaceae.
Mastixia philippinensis Wang. (tapulao). Cornaceae.
Meliosma macrophylla Merr. Sabiaceae.
Melochia umbellata Merr. (labayo). Sterculiaceae.
Memecylon ovatum Sm. (culis). Melastomataceae.
Memecylon paniculatum Jack (culis). Melastomataceae.
Merremia hastata Hallier f. Convolvulaceae.
Merremia umbellata Hallier f. Convolvulaceae.
Mimosa pudica L. Leguminosae.
Mitrephora merrillii C. B. Rob. (lanutan). Anonaceae.
Myristica philippensis Lam. (duguan). Myristicaceae.
Nauclea calycina Bartl. Rubiaceae.
Nauclea media Havil. Rubiaceae.
Neolitsea villosa Merr. Lauraceae.
Nephelium mutabile Blume (bulala). Sapindaceae.
Operculina turpethum S. Manso. Convolvulaceae.
Oreocnide trinervis Miq. Urticaceae.
Ormosia calavensis Blanco (bahay). Leguminosae.
Pahudia rhomboidea Prain (tindalo). Leguminosae.
Palaquium philippense C. B. Rob. (tagatoy). Sapotaceae.
Palaquium tenuipetiolatum Merr. (palacpalac or manicnic). Sapotaceae.
Panicum sarmentosum Roxb. Gramineae.
Parashorea plicata Brandis (bagtican-lauan). Dipterocarpaceae.
Parinarium corymbosum Miq. (liusin). Rosaceae.
Parkia timoriana Merr. (cupang). Leguminosae.
Pentacme contorta Merr. and Rolfe (white lauan). Dipterocarpaceae.
Phaeanthus ebracteolatus Merr. (bamtan). Anonaceae.
Pipturus arborescens C. B. Rob. (dalonot). Urticaceae.
Pisonia umbellulifera Seem. (anuling). Nyctaginaceae.
Pithecolobium scutiferum Benth. (anagap). Leguminosae.
Planchonia spectabilis Merr. (lamog). Lecythidaceae.
Plectronia umbellata K. Sch. (malabacauan). Rubiaceae.
Polyosma philippinensis Merr. (malapandacaqui). Saxifragaceae.
Polyathia lanceolata Vid. (lanutan). Anonaceae.
Polyscias nodosa Seem. (tocod langit or malapapaya). Araliaceae.
Premna cumingiana Schauer (maguili). Verbenaceae.
Pterocarpus indicus Willd. (narra). Leguminosae.

Pterocymbium tinctorium Merr. (taluto). Sterculiaceae.
Pygeum preslii Merr. (uto-uto). Rosaceae.
Radermachera pinnata Seem. (banay-banay). Bignoniaceae.
Reinwardtiodendron merrillii Perk. (malacamanga). Meliaceae.
Saccharum spontaneum L. (talahib). Gramineae.
Sambucus javanicus Bl. Caprifoliaceae.
Santiria nitida Merr. (alupag macsin). Burseraceae.
Sandoricum koetjape Merr. (santol). Meliaceae.
Sarcocephalus cordatus Miq. (bancal). Rubiaceae.
Sarcocephalus junghuhnii Miq. (mambog). Rubiaceae.
Saurauia latebracteata Choisy. Dilleniaceae.
Selaginella belangeri Spring. Selaginellaceae.
Semecarpus cuneiformis Blanco (ligas). Anacardiaceae.
Semecarpus gigantifolius F.-Vill. (ligas). Anacardiaceae.
Schizostachyum mucronatum Hack. (boho). Gramineae.
Shorea eximia Scheff (almon lauan). Dipterocarpaceae.
Shorea guiso Blume (guijo). Dipterocarpaceae.
Shorea negrosensis Foxw. (red lauan). Dipterocarpaceae.
Shorea polysperma Merr. (tanguile). Dipterocarpaceae.
Shorea squamata Dyer (mayapis). Dipterocarpaceae.
Shorea teysmanniana Dyer (tiaong). Dipterocarpaceae.
Shorea robusta Roxb. (sal). Dipterocarpaceae.
Sida javensis Cav. Malvaceae.
Sideroxylon duclitan Blanco (duclitan). Sapotaceae.
Streblus asper Lour (kalios). Moraceae.
Streptocaulon baumii Decne. Asclepiadaceae.
Strombosia philippinensis Rolfe (tamayuan). Olacaceae.
Synedrella nodiflora Gaertn. Compositae.
Symplocos oblongifolia Rolfe. Symplocaceae.
Tabernaemontana pandacaqui Poir. (pandacaqui). Apocynaceae.
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Urandra luzoniensis Merr. (mabunut). Icacinaceae.
Vitex parviflora Juss. (molave). Verbenaceae.
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PLATE II.

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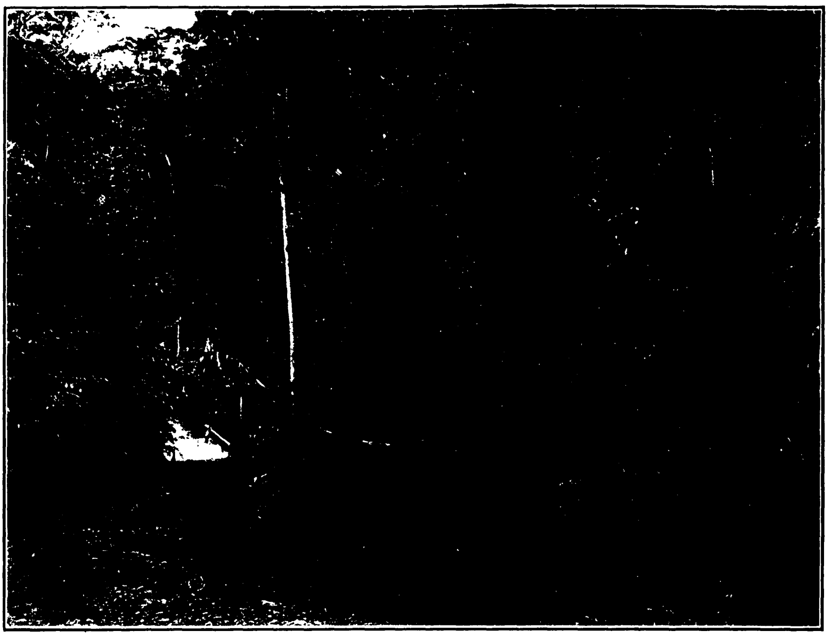

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